COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

September 1956

Arizona Public Service's Saguaro Power Plant—a completely outdoor station.

Experimental Russian Supercritical Pressure Boiler

Outdoor vs Indoor Power Plants

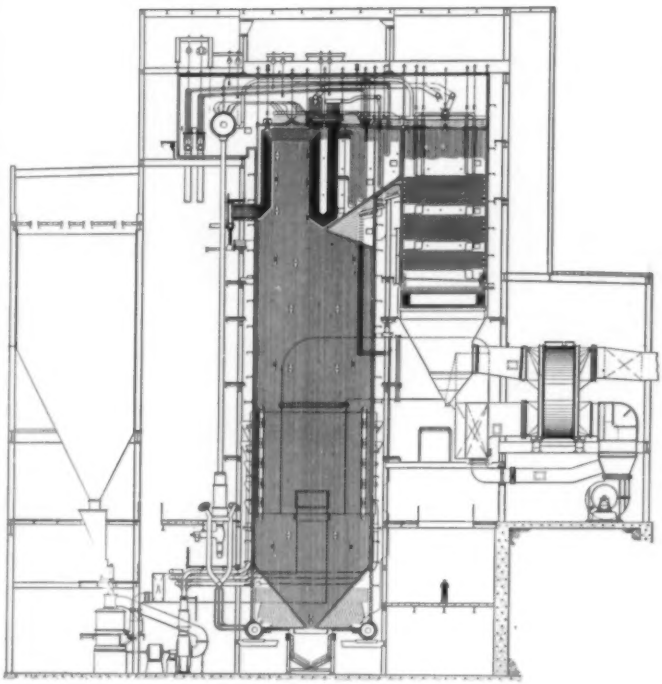
Bubble Contact Heaters for Power Plants

International Combustion Symposium

ALLEN PLANT

Duke Power Company

C-E controlled circulation boilers



The C-E Unit shown above is one of two duplicate units now in process of fabrication for the Allen Plant of the Duke Power Company at Belmont, North Carolina.

Each of these units is designed to serve a 165,000 kw turbine-generator operating at a throttle pressure of 2350 psi with a primary steam temperature of 1050 F, reheated to 1000 F.

These units are of the controlled-circulation, radiant reheat type with convection reheater surface located between the primary and secondary superheater surfaces, and radiant reheater surface of the platen type intermeshed with radiant superheater platen surface at the top of the furnace.

On these units an economizer section follows the rear superheater section and regenerative type air heaters follow the economizer surface.

Pulverized coal firing is employed using bowl mills and tilting, tangential burners.

B-945

COMBUSTION ENGINEERING, INC.

Combustion Engineering Building
200 Madison Avenue, New York 16, N. Y.

STEAM GENERATING UNITS; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; HOME HEATING AND COOLING UNITS; DOMESTIC WATER HEATERS; SOIL PIPE

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 28 **No. 3**

September 1956

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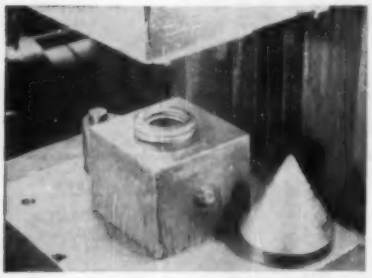
BPA

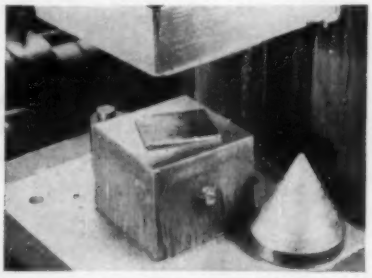
Printed in U. S. A.

These extras make ELECTRUNITE

	TESTS	ELECTRUNITE BOILER TUBES	ASTM A-178 ASME SA-178	ASTM A-226 ASME SA-226	A.A.R. M-108	SEE NOTE*	FEDERAL WW-T-731b	MIL-T-17188	MIL-T-20160	MIL-T-20162 MIL-T-20169
Before Welding	Chemical Composition	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Gage Check	✓								
Production Control	Flattening	✓								
	Reverse Flattening	✓								
	Expansion	✓								
	Flange	✓								
	Metallurgical Laboratory	✓								
Finished Tube	Flattening	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Flange	✓	✓	✓	✓	✓	✓	✓		
	Crush	When Required	When Required		When Required	When Required				
	Reverse Flattening	✓	✓	✓		✓				
	Tensile	✓							✓	✓
	Hydrostatic	✓	✓	✓	✓	✓	✓	Optional	✓	✓
	Non-Destructive Electric	When Required	In lieu of Hydrostatic	In lieu of Hydrostatic			In lieu of Hydrostatic	All or part required		Optional
	Final Inspection	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Protective Coating	✓					✓	✓		

*NOTE: Tests in this column specified in American Bureau of Shipping, Sec. 40 par. 66-83; Treasury Dept., U. S. Coast Guard-Marine Engineering Regulations 51.01, 51.25, 51.28, 51.34.





THESE TESTS ARE TYPICAL of those listed in the chart above, showing: 1, axial crush test; 2, flatten test with weld at point of maximum bend; 3, hydrostatic test of each completed tube, at a pressure in excess of code requirements.

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World's Widest Range of Standard Steels

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This program assures quality from raw ore to finished product and includes not only all tests required by applicable specifications (see chart), but *complete production control tests* during manufacture, as well. In addition, Republic alone offers FARROWTEST®, the electronic nondestructive test, which, when you specify it, peers *inside* your tube walls to detect and reject any flaws. Republic quality, verified by FARROWTEST, will meet the strictest specifications. It is your best evidence that ELECTRUNITE Boiler Tubes, when properly installed and maintained, will give years of dependable, trouble-free service.

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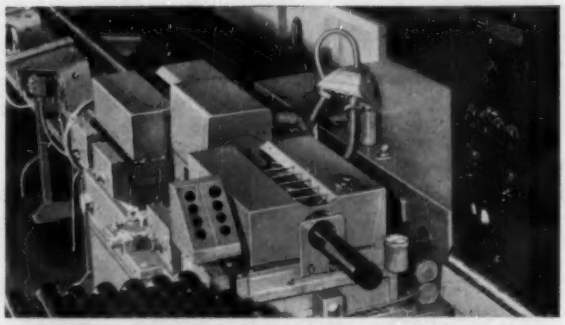

FARROWTEST . . . DEVELOPED BY REPUBLIC is the most conclusive, nondestructive tubing test in use today. Electronically operated, its detector coils can spot defects in tube walls which would be hidden from routine test procedures. You can specify FARROWTEST on ELECTRUNITE Boiler Tubing instead of your present method at no extra cost.

UNIFORMITY IS THE KEY to easier, faster installation when you use ELECTRUNITE Boiler Tubes. They slide into headers and drums easily, expand evenly with less rolling, and bead over quickly. Republic manufacturing methods "build-in" uniform wall thickness, diameter, strength, ductility, microstructure and surface. Testing verifies these characteristics in each tube you receive.

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K-8928

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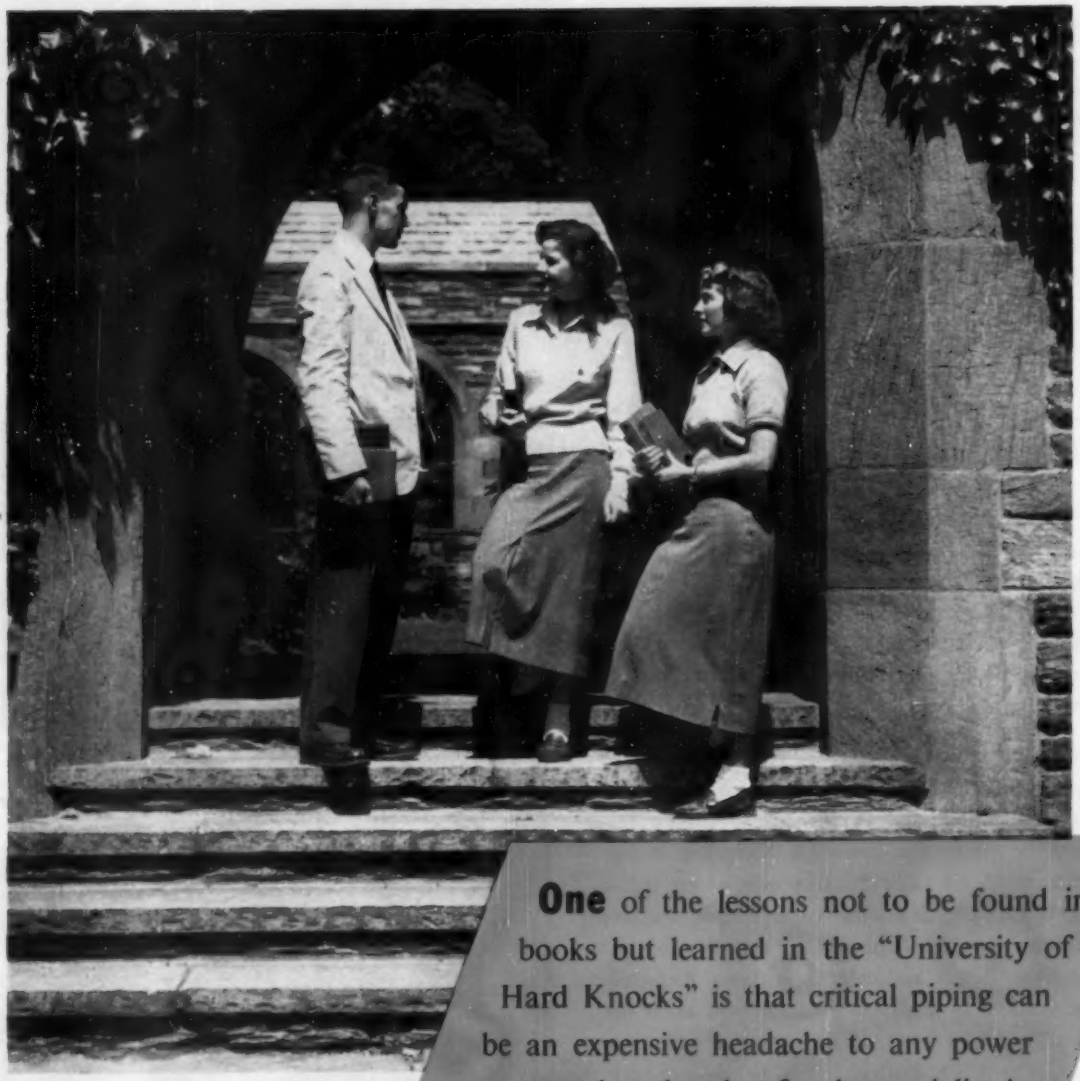
and Steel Products



One of the lessons not to be found in books but learned in the "University of Hard Knocks" is that critical piping can be an expensive headache to any power or processing plant but for the specialized experience of experts. On your next high-temperature, high-pressure job, ask us in.

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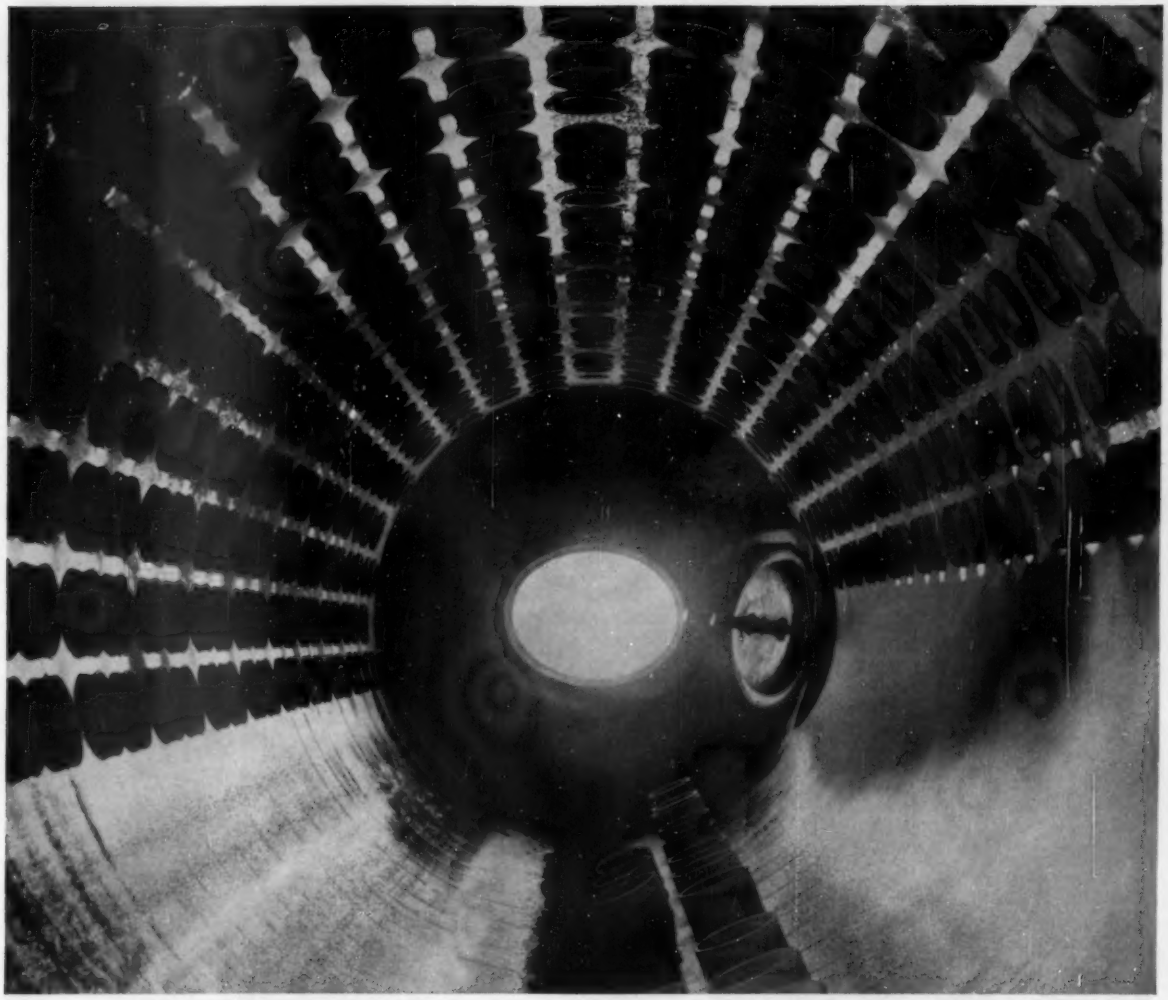

Mud drum interior of Boiler No. 9, American Motors Co., Kenosha, Wis.

NO TROUBLE HERE...

When the mud drum of Boiler No. 9 was drained and opened for inspection recently, the interior looked exactly the way everyone expected it would—clean as a whistle. After nine months of service there was no sludge or scale to impair steam production efficiency.

This kind of trouble-free performance and the continuous production of high-purity steam are direct results of Dearborn Water Conditioning—a properly balanced program that combines quality products with the right methods, controls, and technical supervision.

Power Engineers in leading industrial plants throughout the country place their confidence in Dearborn methods and products. A Dearborn Water Conditioning program in your power plant is your assurance of maximum operating efficiency—and your insurance against unnecessary maintenance expense and costly shutdowns caused by sludge, scale or corrosion.

Let a Dearborn Water Treatment Engineer survey your system and recommend control methods best suited to your needs. We'll gladly make the call at your convenience.

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☐ Please have a Dearborn Engineer call.

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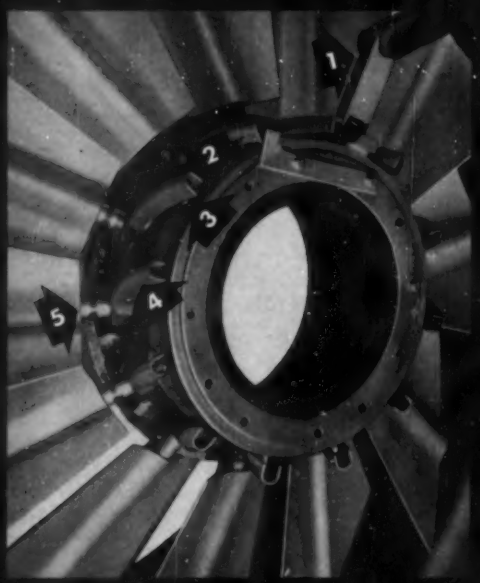
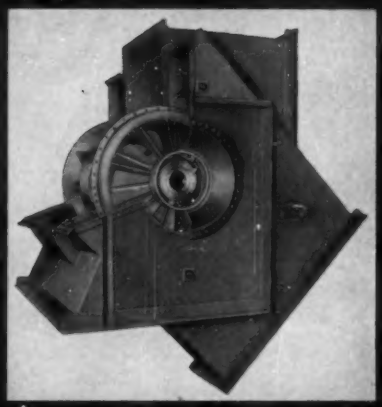
...a leader in water conditioning and corrosion control since 1887

Fact:

STURDY WESTINGHOUSE-STURTEVANT INLET SPIN CONTROL SAVES FAN POWER WITH CONSTANT-SPEED MOTORS





Operating mechanism is shielded from the gas stream but is readily accessible from the outside for inspection and maintenance.

5-POINT POSITIVE OPERATION. As link and lever (1) moves the operating ring (2) hardened steel spherical pins (3) turn crank arms (4) welded to the tubular vane cores (5). Each vane turns on a heavy steel rod anchored between the center mechanism and outer steel support. No lubrication is required.

SPIN CONTROL CUTS OPERATING COST

The combination of Westinghouse Inlet Spin Control and the simple squirrel cage constant speed motor is less costly to install and provides greater overall power savings than other types of mechanical draft control.

SMOOTH, SIMPLE ACTION

Inlet Spin Control has no gears—no backlash. Provides instantaneous control of draft. Vanes move rapidly in the open range, yet fine adjustment is possible in the near-closed position. Extremes of heat and cold do not affect its operation in any way.

MOST EFFICIENT, MOST ECONOMICAL

In any comparison of both forced and induced draft fans and their control devices, you will find Inlet Spin Control is both the most efficient and economical choice.

MORE FACTS?

Call your nearest Westinghouse-Sturtevant Sales Engineer . . . he's the "Man with the Facts". . . or fill in the coupon below.

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Westinghouse Electric Corporation
Sturtevant Division, Dept. 2J
Hyde Park, Boston 36, Mass.

Please send more facts on Inlet Spin Control.

NAME AND TITLE.....

COMPANY.....

CITY.....STATE.....

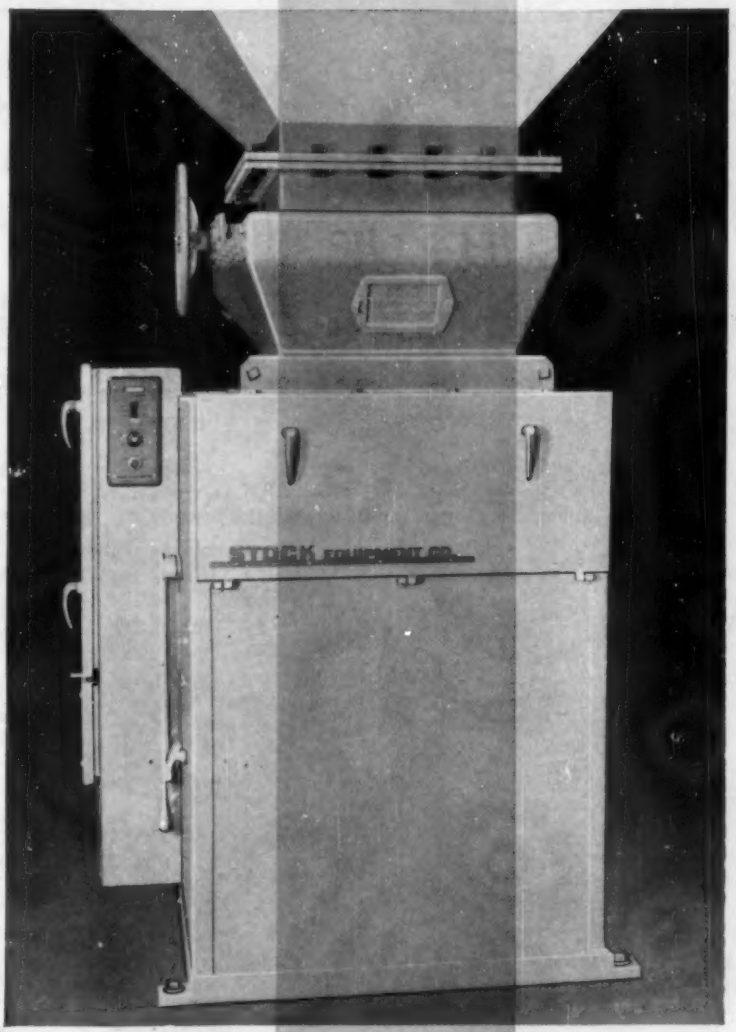
THE NEW S-E-CO. MODEL 50

COAL SCALE is the only scale that carries a 24" width of coal through the scale without restriction

To meet the requirements of central stations and industrial plants that are using larger and larger boilers — and to move coal that is becoming more and more sluggish — Stock Equipment Company has developed their new Model 50 Automatic Dust-Tight Coal Scale.

The inlet is a full 24" inside square and the feed belt carries the coal straight through in an unrestricted 24" stream. The belt has the well known S-E-Co. endless, molded construction and is carried on closely spaced anti-friction idlers. This design allows it to handle the inlet loading (even under the largest bunkers) without danger of belt failure or shortened life.

The Model 50 includes many other new and advantageous features. Contact the Main Office in Cleveland or any of the local representatives to arrange for a conference to discuss these features in detail. Your next unit, whether it's brand new or part of a rebuilding program, deserves and needs the new S-E-Co. Model 50.



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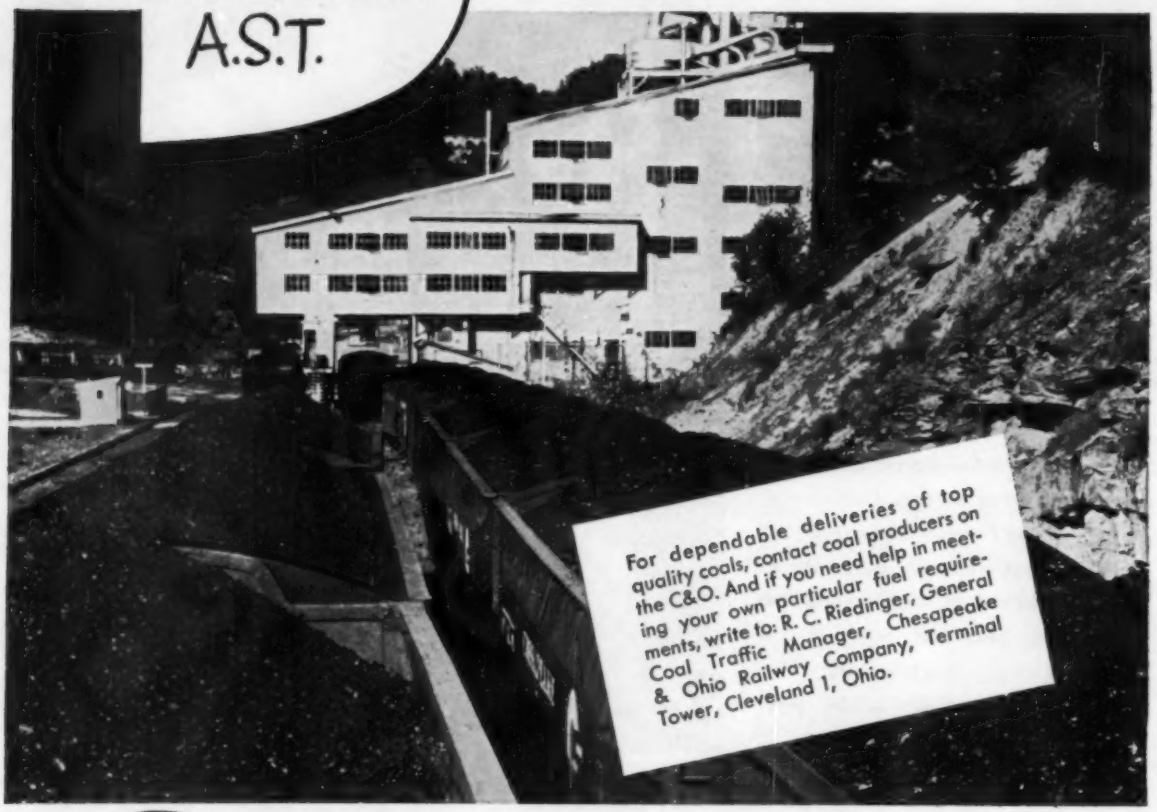
STOCK Equipment Company

745-C HANNA BLDG., CLEVELAND 15, OHIO

Write your own specifications:

VOLATILITY
B.T.U's
SIZE
ASH
MOISTURE
SULPHUR
A.S.T.

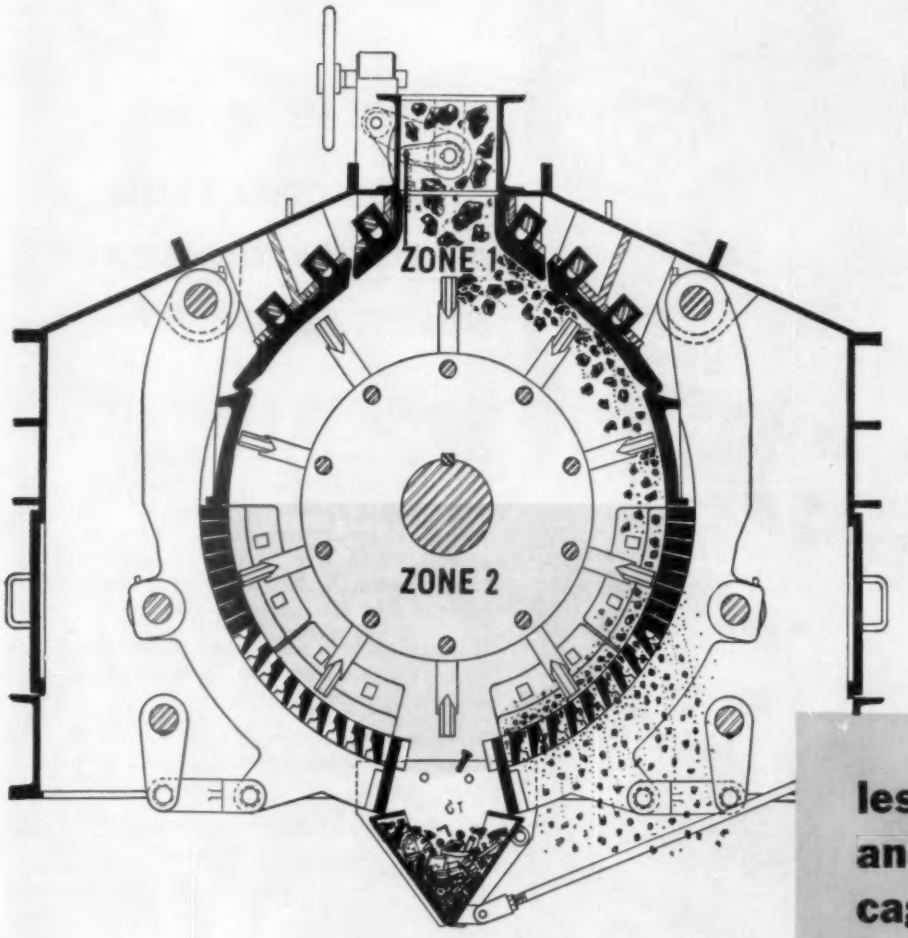
. . . the modern, efficient mines on the C&O can produce just what you want.


For dependable deliveries of top quality coals, contact coal producers on the C&O. And if you need help in meeting your own particular fuel requirements, write to: R. C. Riedinger, General Coal Traffic Manager, Chesapeake & Ohio Railway Company, Terminal Tower, Cleveland 1, Ohio.

Chesapeake and Ohio Railway

WORLD'S LARGEST CARRIER OF BITUMINOUS COAL

very little attrition here



less hammer and cage wear

Take a careful look at the illustration above. See how most of the size reduction of the coal takes place in zone 1 by free air impact, breaking along the lines of natural cleavage. Only after particle size has been greatly reduced does the coal reach zone 2, where hammers force it through the screen bars. Due to several adjustable features the operator has the option of various product sizes, making this the ideal coal preparation crusher for stokers, pulverizers or cyclone furnaces. Parts wear and power consumption are held to a minimum. And remember, the reversible feature greatly increases hammer life and eliminates down time and labor cost of manually turning hammers.

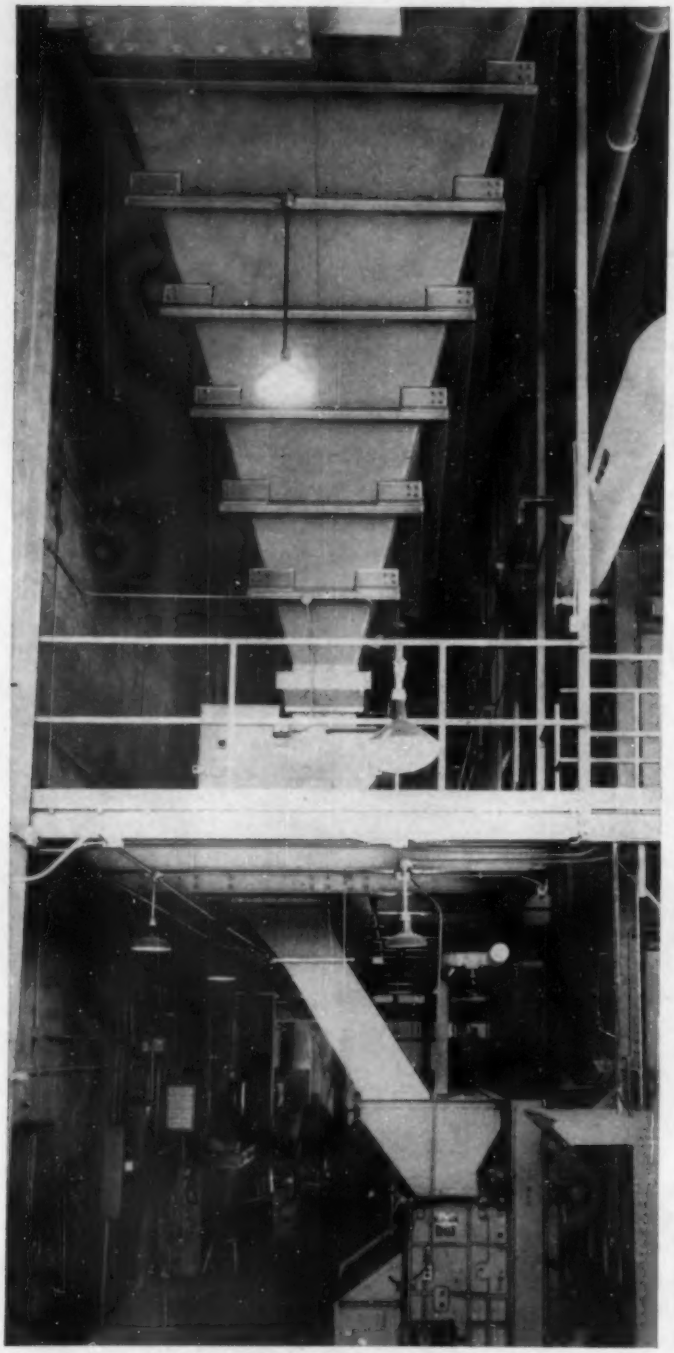
PENNSYLVANIA

REVERSIBLE HAMMERMILL

PENNSYLVANIA CRUSHER DIVISION

Bath Iron Works Corporation • West Chester, Penna.

PE-209



One more new installation of Lukens Type 304 *stainless-clad* steel – these smooth-operating coal hoppers and chutes, fabricated by Fairfield Engineering Company, Marion, Ohio, feed through second-floor scales to boiler.

Clad Steel Chosen Again...

STEADY COAL FLOW A MUST IN NEW STATE HOSPITAL PLANT!

Hospitals can't take a chance on power interruptions from coal hangups. In Wisconsin's Mendota State Hospital, three *stainless-clad* steel coal hoppers and chutes, three-stories high, assure smooth, dependable coal flow. In more and more coal handling installations, clad steel is being specified because of these *demonstrated* advantages:

- Substantial economies from lower maintenance costs in chutes, hoppers, bunkers, pipes and spreaders.
- Freedom from hangups and the damaging and costly effects of sulfuric acid corrosion from wet coal.
- Toughness proved by *installations 10 years old which showed no measurable wear!*
- Evidence of service life that matches the life of the boiler!

PLUS: ready fabrication . . . permanence of bond between stainless steel cladding and strong, low-cost carbon steel backing . . . over-all quality that delivers lower maintenance costs, longer life, and trouble-free operation.

Bulletin 740 will give you performance facts and product information to help your engineers make the most of clad steel. For this bulletin, as well as the names of some of the nation's best and most experienced coal handling equipment builders, write Manager, Marketing Service, 845 Lukens Building, Lukens Steel Company, Coatesville, Pa.

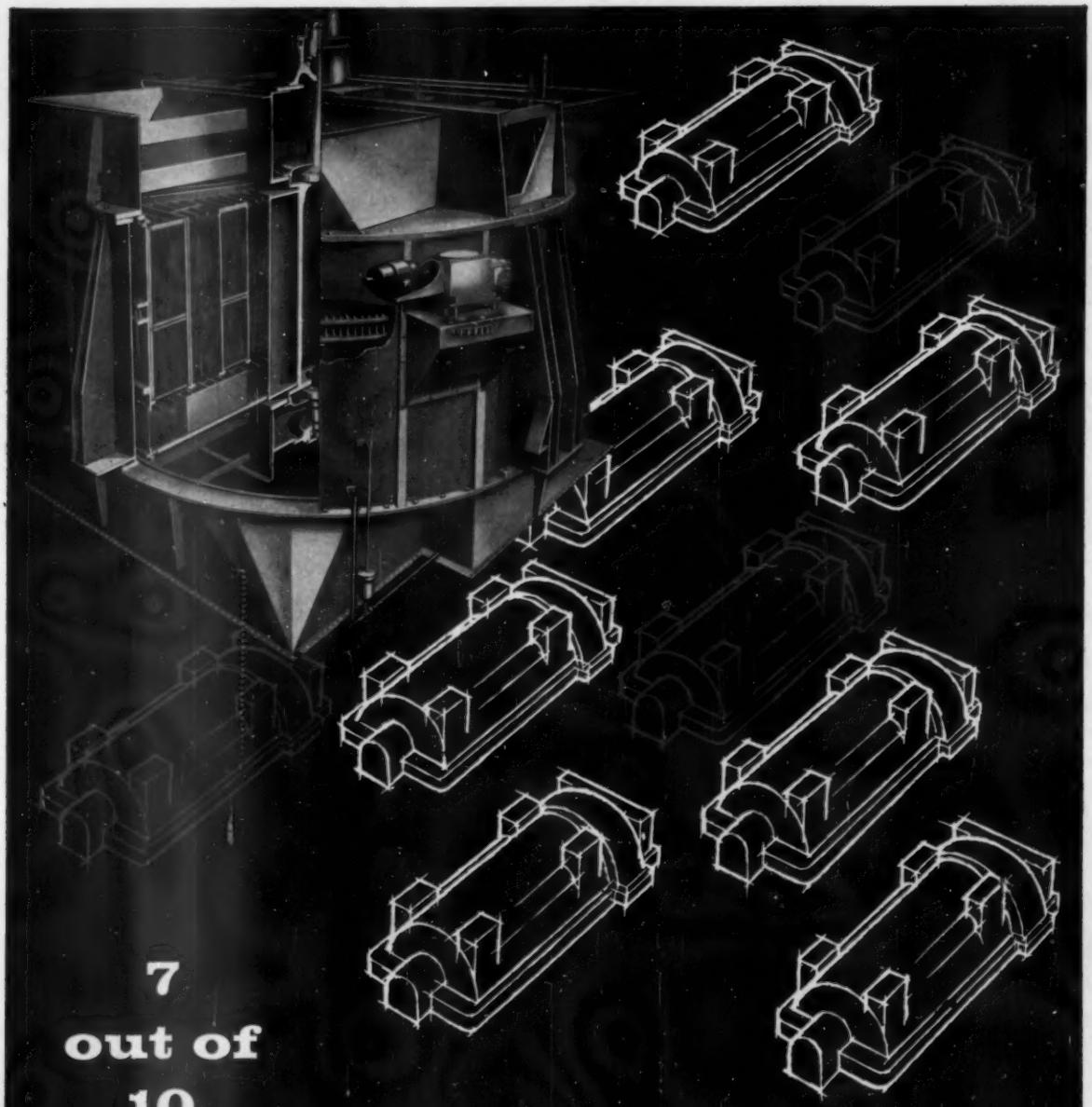
STAINLESS-CLAD STEELS

LUKENS

FOR INTERIOR COAL HANDLING EQUIPMENT

LUKENS STEEL COMPANY, COATESVILLE, PENNSYLVANIA

Producers of the Widest Range of Types and Sizes of Clad Steel Available Anywhere



7 out of 10

air preheater installations are Ljungstrom®

Advantages of the Ljungstrom Air Preheater

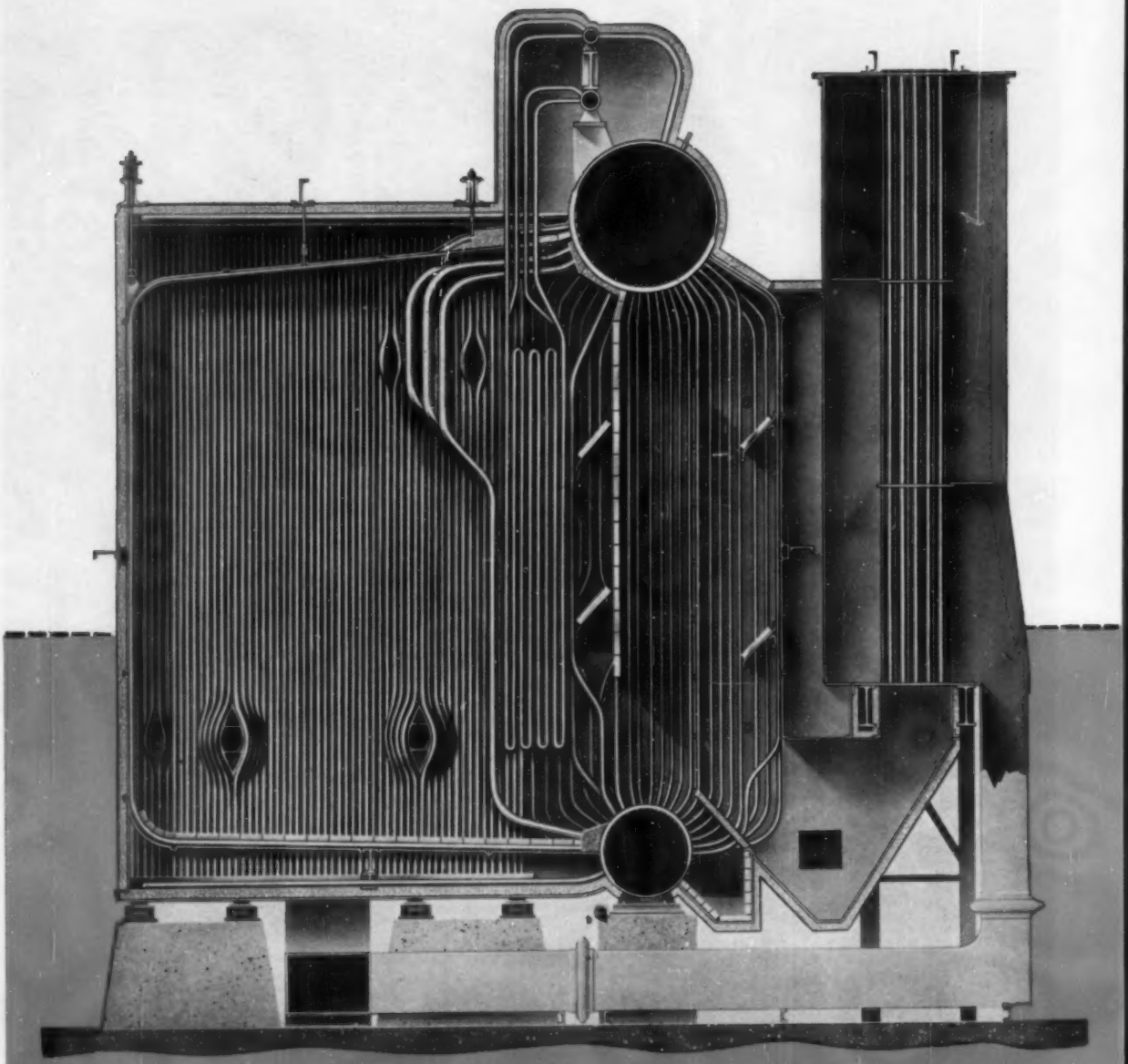
- Size for size, recovers far more heat than any other type.
- Reduces fuel consumption. Permits use of lower grade fuels. Increases boiler output and reliability.
- Eliminates cold spots . . . keeps corrosion to a minimum.
- Easier, faster to clean and maintain.
- Requires far less supporting steel and is quickly erected.

MINIMUM MAINTENANCE is one of the many important reasons. More complete combustion of fuel results in far less slagging, and gases entering dust-recovery units are cleaner. There's less corrosion. Insertion of new elements can be done in as short a time as four hours. You can even inspect the Ljungstrom through a built-in port while the unit is in operation.

For the interesting full story, send for a free copy of our 38-page manual.

The Air Preheater Corporation 60 East 42nd Street, New York 17, N. Y.

THE VU-55...



SPECIFICATIONS

Sizes—Five sizes ranging from 50,000 to 120,000 lb of steam per hr.
Pressures—250 up to 750 psi (all sizes)
Superheat—as required up to 300° F
Fuels—oil or gas, pressure fired
Heat Recovery—Tubular or Regenerative Air Preheater

AN OUTSTANDING BOILER BUY FOR CAPACITIES FROM 50,000 TO 120,000 LB. OF STEAM PER HOUR!

The VU-55 — a development of Combustion's basic Vertical Unit design—offers features never before available in a boiler of its capacity range. If your steam needs call for a unit in the 50,000 to 120,000-lb class, you will find it worth while to consider the economic and operating advantages assured by these VU-55 features:

TANGENTIAL FIRING. More than 20 years of application experience have established the exceptional advantages of tangential firing, illustrated and briefly described below. About 90 percent of Combustion's large utility installations use this advanced method of firing.

DOUBLE WALL, PRESSURIZED CASING. The latest development in casing construction for pressure firing of boilers in the size class of the VU-55, this casing as illustrated and described below, is designed to assure life-time tightness with minimum heat loss. Pressure firing permits the elimination of an induced draft fan with its attendant operating and maintenance costs.

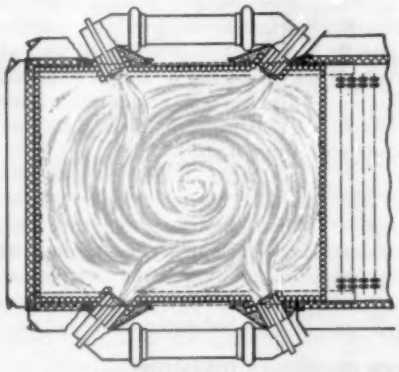
TANGENT FURNACE TUBES. The VU-55's furnace tube arrangement provides complete heat-absorbing, water-cooled protection on all furnace walls. Furnace maintenance is minimized, refractory expense is eliminated, heat absorption rates per sq ft are higher.

SIMPLIFIED ERECTION. Shop assembly of furnace wall panels and boiler screen tubes saves time and money in handling, transportation and erection.

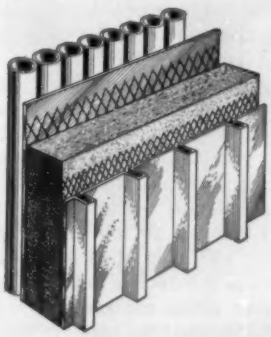
HIGH STEAM QUALITY. Equipped with a large (60-in.) steam drum, the VU-55 has generous water capacity and steam reservoir space. C-E drum internals assure high quality steam at all ratings.

STREAMLINED EXTERIOR. The over-all appearance of the VU-55 reflects the efforts of its designers to achieve a completely unobstructed casing, while retaining adequate access wherever required and every facility for convenient operation. There are no outside downcomer tubes, and ducts from air heater to burners are beneath the furnace floor.

Your request for further information on the VU-55 Boiler will receive prompt attention.



PLAN VIEW OF FURNACE showing arrangement of burners for tangential firing. Flame streams from the four burners impinge upon one another at high velocity, creating a turbulence unattainable by any other method of firing. The result is rapid and complete combustion. As the gases spiral upward, they sweep all furnace heating surfaces, assuring a high rate of heat absorption.



PERSPECTIVE OF FURNACE WALL. Construction consists of tangent tubes backed up successively by welded steel panels, 4 inches of high quality insulating material and an outer steel casing formed as shown to provide adequately for expansion and assure ample strength. Low heat loss and the tightness required for pressure firing are assured by this double-wall construction.

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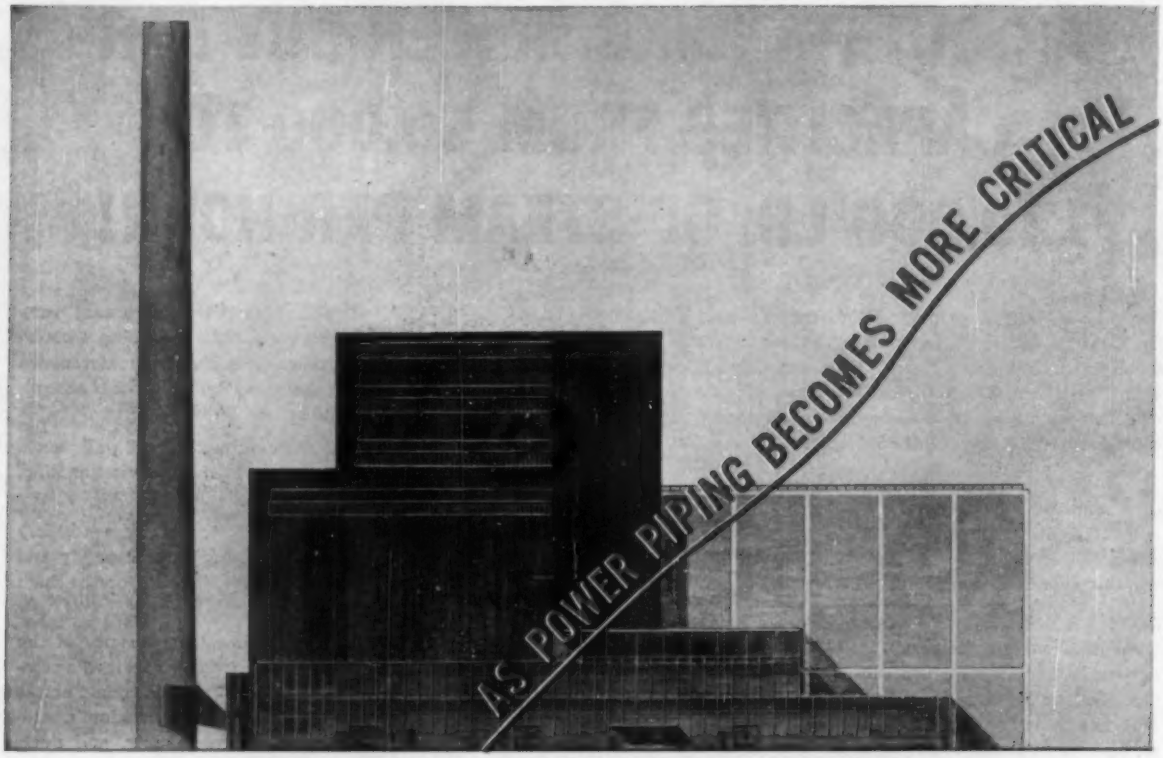
CANADA: COMBUSTION ENGINEERING-SUPERHEATER LTD.

B-938

STEAM GENERATING UNITS; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; HOME HEATING AND COOLING UNITS; DOMESTIC WATER HEATERS; SOIL PIPE



Architect's sketch of Philadelphia Electric Company's new Eddystone station

Kellogg's High Alloy Fabrication Keeps Pace

Designed to operate at 5000 psi at turbine throttle valve, and 1200 F., Unit No. 1 at Philadelphia Electric Company's new Eddystone station presented critical problems in the selection of an alloy for supercritical pressure piping, and in techniques for fabricating heavy-walled sections of this alloy in the shop and in the field.

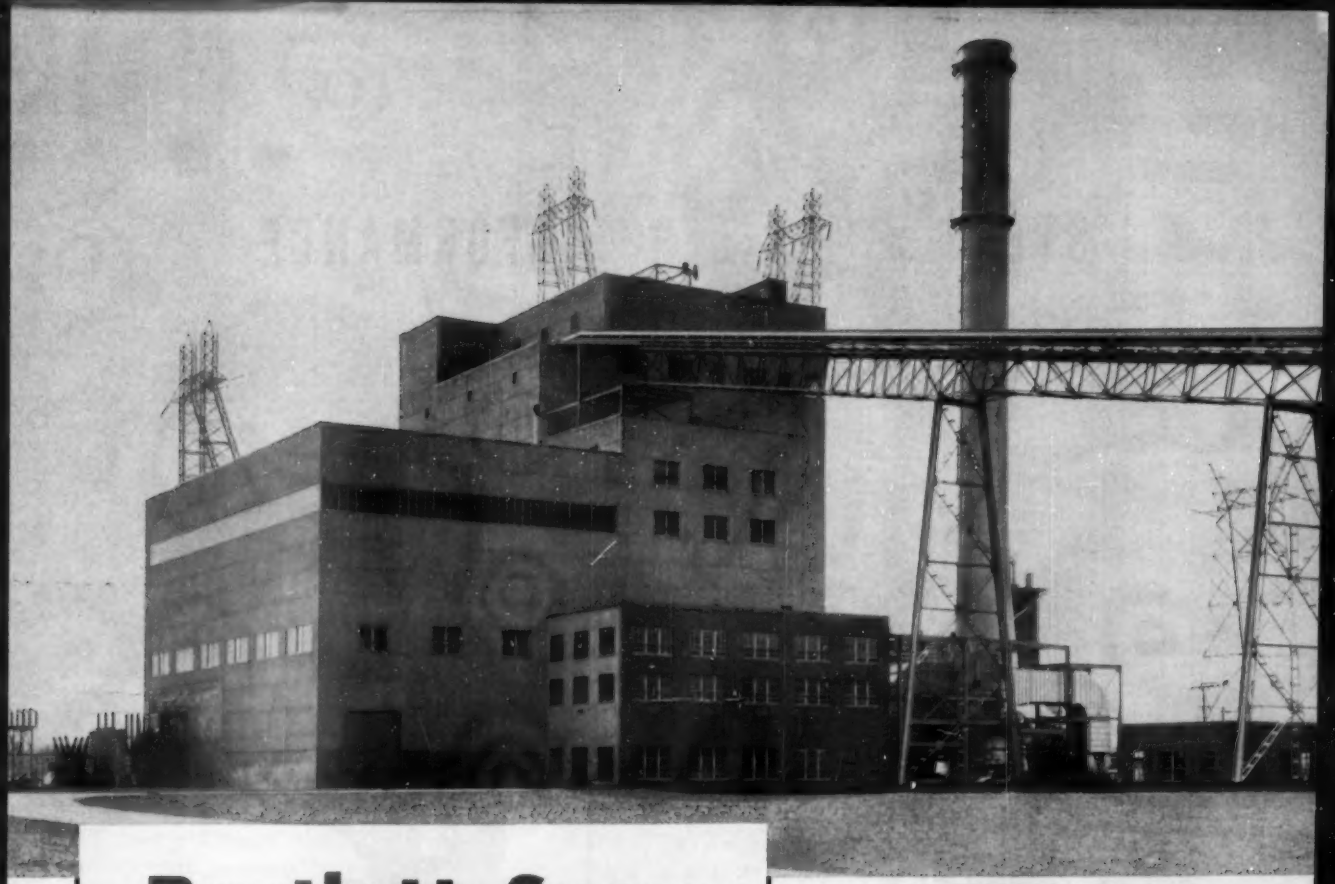
More than a year ago, The M. W. Kellogg Company presented a comprehensive program to the Philadelphia Electric Company for selecting a suitable alloy, and since then has been working closely with this public utility and other prime contractors toward completion of the project. Numerous materials were studied, welded, tested, heat treated, and evaluated at Kellogg's Jersey City metallurgical laboratories. After many months of extensive and intensive work, Type 316 Stainless was selected. M. W. Kellogg has already perfected welding techniques, and is now continuing tests on this alloy and several other compositions, including strain aging for 1000 hours and 10,000 hours at 1300 F., to accumulate other data.

While this is the first time that Type 316 will have been used in power plant service for temperatures as high as 1200 F., and pressures as much as 5000 psi, it is by no means Kellogg's first experience with Type 316 or other stainless steels. For example, M. W. Kellogg recently undertook metallurgical studies and research for another large public utility prior to its selection of Type 316 for use at 1100 F. and 2400 psi. Kellogg also has done considerable fabrication of main steam lines and turbine leads, using Type 347.

The M. W. Kellogg Company welcomes the opportunity of discussing future power piping requirements with consulting engineers, engineers of power generating companies, and manufacturers of boilers, turbines, and allied equipment.

FABRICATED PRODUCTS DIVISION
THE M. W. KELLOGG COMPANY, 711 THIRD AVENUE, NEW YORK 17, N. Y.
A SUBSIDIARY OF PULLMAN INCORPORATED
The Canadian Kellogg Company Ltd., Toronto • Kellogg International Corp., London • Kellogg Pan American Corp., New York • Societe Kellogg, Paris • Companhia Kellogg Brasileira, Rio de Janeiro • Compania Kellogg de Venezuela, Caracas

POWER PIPING—THE VITAL LINK

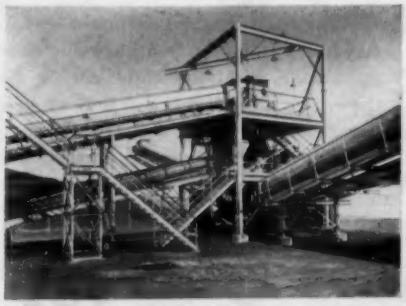


General View of Herbert A. Wagner Station
Baltimore Gas and Electric Company
Baltimore, Maryland

Bartlett-Snow coal handling at Baltimore

● The coal handling system for the initial 125,000 kw unit at Baltimore Gas and Electric Company's Herbert A. Wagner Station, including car dumper receiving hoppers, apron feeders, and 36" wide belt conveyors to and from storage and with shuttle belt distribution to plant bunkers, was designed by Bartlett-Snow in cooperation with Baltimore Gas and Electric Company's engineers and installed, including the breaker, by the Bartlett-Snow erection department. Provision was made so that the present system of 450 tons per hour capacity can be increased to 900 tons per hour. For maximum efficiency and economy let the Bartlett-Snow coal handling experts work with you on your next new plant, plant extension or modernization program.

View of Yard from Top of Station
Showing Conveyor System.



View of Transfer Station. Coal Chutes to Conveyor to Boiler House or Yard Storage.

DESIGNERS
ENGINEERS

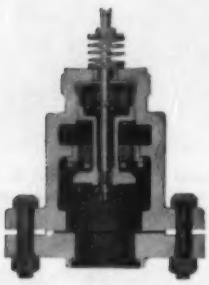
BARTLETT-SNOW
CLEVELAND 5, OHIO

FABRICATORS
ERECTORS

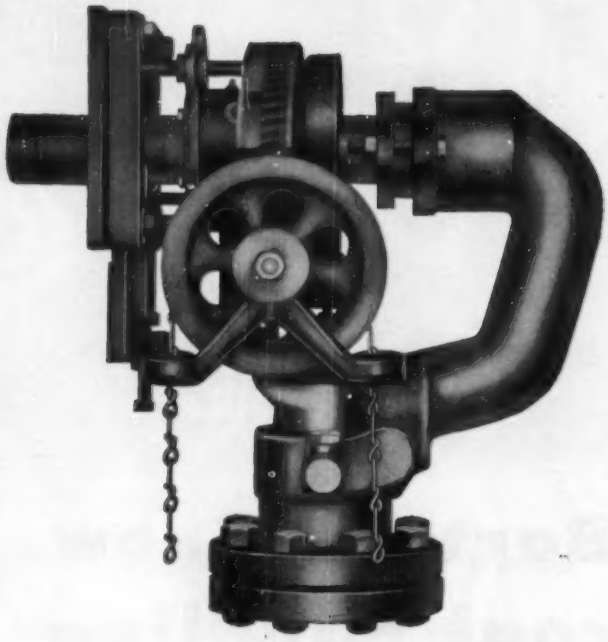
"Builders of Equipment for People You Know"

BAYER
STEPS UP BOILER PERFORMANCE

DISTINCTLY DIFFERENT



Bayer Balanced Valves are famous for their long life and continued tightness



Bayer Single Chain Balanced Valve Soot Cleaner

WITH THE Bayer Balanced Valve Soot Cleaner the balancing chamber above the piston disc impounds steam when the valve closes, thus relieving valve parts from shock. The valves remain *steam tight* because the dashpot action causes the valve to seat gently. Unbalanced valves close with a hammer stroke and soon become leaky.

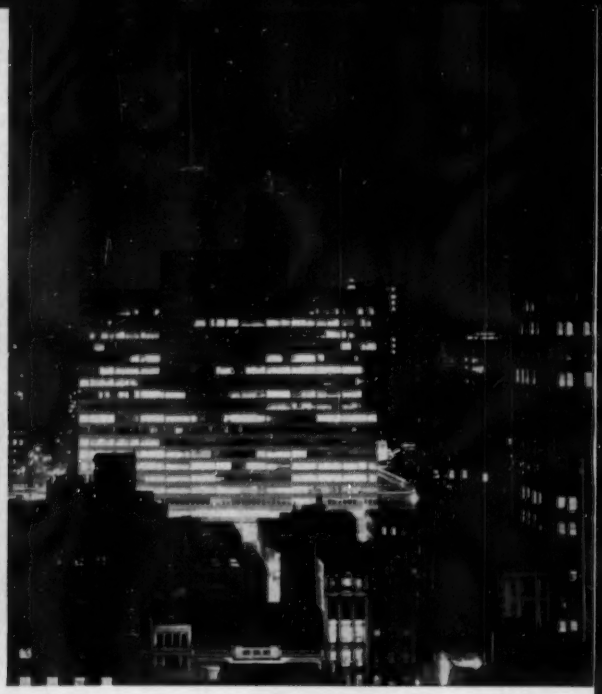
When stationary elements are used the Bayer stationary balanced valve head may be furnished. Thus all the cleaning elements of the entire soot cleaner system can be controlled by the Bayer quick-opening Balanced valves. This gives a uniform or standard valve controlled system and in addition, when high pressures require a reduction in pressure *at each individual element* this Balanced valve unit, whether used with a stationary or a revolving element, can be fitted with an integral orifice plate valve.

Piping connections can be kept in the same plane and undesirable bends or fittings avoided when the Bayer Balanced Valve is installed with both stationary and revolving elements.

Valve parts are standard and interchangeable and when high pressure heads are fitted with orifice plate regulating valves these parts are also interchangeable.

THE BAYER COMPANY

SAINT LOUIS, MISSOURI, U. S. A.



GENERAL REFRACTORIES

you live with BRICK . . . 24 hours a day!

365 days and nights a year, you come in contact with products born in and from refractory brick.

Your office and everything in it. Everything you see and touch . . . everything that's made or moves owes its very existence to refractory brick. Refractories—containing and controlling the flames of industry—produce the steel, electric power, rubber and cement you use *continuously* in daily living.

And the making of refractory products is the most basically necessary industry there is.

Refractories, you see, create industry . . . without them, there would be no industry.

Providing industry with Castables, Plastics, Ramming Mixes, Fire Brick, Mortars, Insulating Brick and Insulation, General Refractories Company draws resources from all over the globe—and operates the world's largest, most-modern refractories research laboratory.

A Complete Refractories Service

GENERAL REFRACTORIES COMPANY

Philadelphia 2, Pa.

A COMPLETE REFRACTORIES SERVICE FOR STEAM GENERATION

Monolithic furnace linings of GREFCO plastic firebrick are economical and will provide long uninterrupted service. Three high quality mixes are available for various furnace conditions with a selection of well engineered refractory and high temperature alloy metal anchors for various combinations and thicknesses.

GREFCO plastics are manufactured at three strategically located plants in Pennsylvania, Missouri and Georgia. Stocks are maintained for prompt truck delivery at all company warehouses and dealers in principal cities.

When you specify GREFCO you are assured of quality second to none. The world's finest and best equipped refractory laboratory is constantly developing new products and improving old ones. District laboratories constantly check raw materials and finished products. GREFCO places great emphasis on uniform high quality.

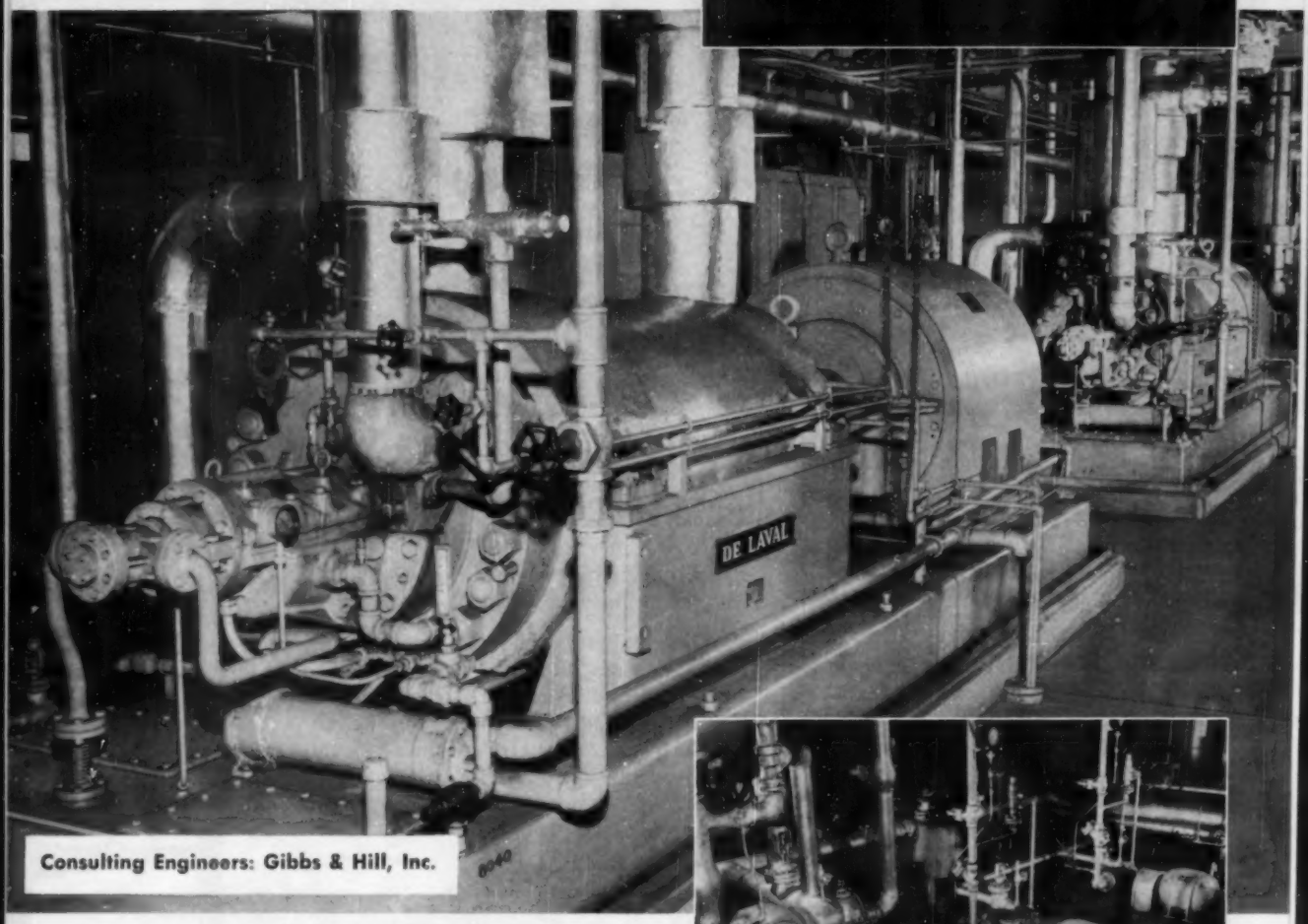
SUPER BRIKRAM MIX-G—a super duty quality plastic firebrick with a special binder which provides an airset when material is air dried. Provides high strength throughout the entire thickness of the wall or arch.

SUPER BRIKRAM—a plastic firebrick of super duty quality for furnace linings where conditions warrant the use of super duty quality. Has excellent resistance to spalling and high temperatures.

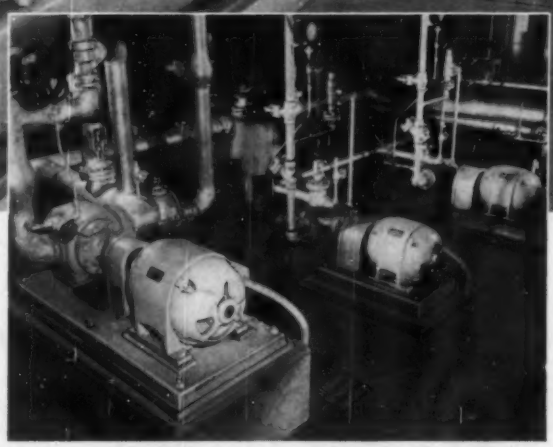
BRIKRAM—a plastic firebrick of high duty quality. Excellent for patching or complete furnace linings where conditions do not require a super duty quality refractory.

Atlantic City Electric ... another utility using

DE LAVAL
BARREL TYPE BOILER FEED PUMPS



Consulting Engineers: Gibbs & Hill, Inc.



De Laval IMO rotary positive displacement pumps handle heavy fuel oil. They are used for standby operation.

Atlantic City Electric Co. and Gibbs & Hill, Inc., Consulting Engineers, know that they can count on De Laval reliability. That's why they selected three De Laval high pressure barrel type boiler feed pumps for the Deepwater Station in Penns Grove, New Jersey. These 10-stage units deliver 675 gpm, operating at 1762 psi with temperature at 287 F. The pumps are driven by 900 hp motors.

De Laval barrel type boiler feed pumps operate at pressures up to 5500 psi. These units offer many important design advantages, such as double volute diaphragm, individual diaphragm bolting, only one inner high-pressure joint, and bare shaft construction. Their dependability is proven by year in, year out service in public utilities and industrial plants.

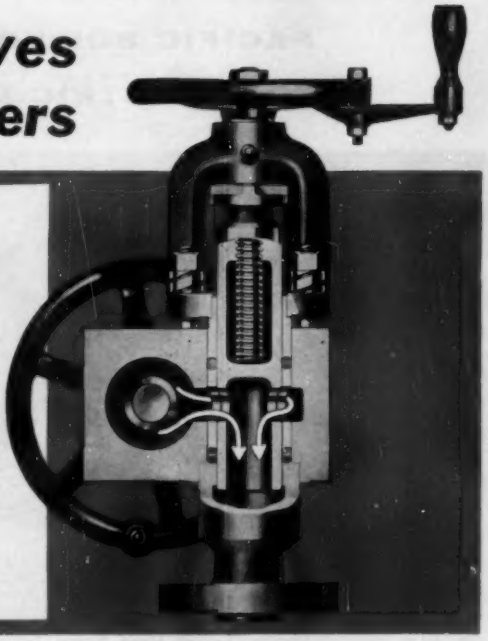
Readers of this publication can obtain the De Laval Engineering Handbook (Regular Price $3.00) for one dollar. Its 336 pages contain mathematical, mechanical, fluid and other data on turbines, pumps, compressors and reduction gearing. Write for your copy.

DE LAVAL *Boiler Feed Pumps*

DE LAVAL STEAM TURBINE COMPANY
6 Nottingham Way, Trenton 2, New Jersey

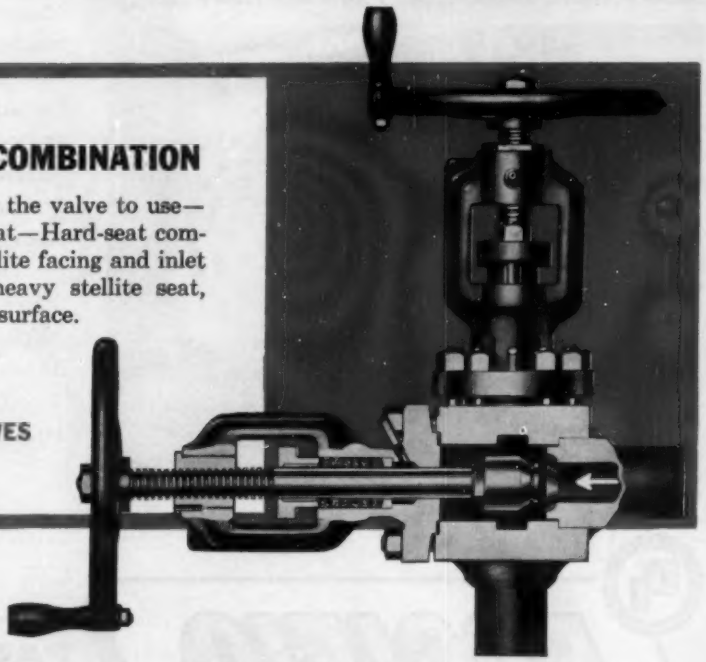
UNIT TANDEM

rugged blow-off valves for high pressure boilers



HARD-SEAT—SEATLESS COMBINATION

■ For boilers up to 1500 psi, this Yarway Unit Tandem Blow-Off Valve offers the maximum in dependable service. A one-piece forged steel block serves as the common body for the Yarway Stellite Hard-seat blowing valve and the Yarway Seatless sealing valve. All interconnecting flanges, bolts and gaskets are eliminated. The Unit Tandem at right is sectioned through Seatless Valve to show balanced sliding plunger in open position and free flow.



HARD-SEAT—HARD-SEAT COMBINATION

■ For boilers to 2500 psi, this is the valve to use—Yarway's Unit Tandem Hard-seat—Hard-seat combination. Disc has welded-in stellite facing and inlet nozzle has integral welded-in heavy stellite seat, providing smooth, hard-wearing surface.

OVER 4 OUT OF 5
HIGH PRESSURE PLANTS
USE YARWAY BLOW-OFF VALVES

Write for Yarway Catalog B-434

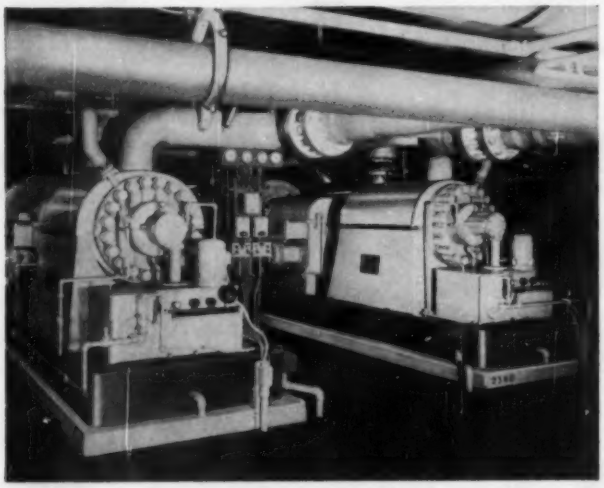
YARNALL-WARING COMPANY
100 Mermaid Ave., Philadelphia 18, Pa.
BRANCH OFFICES IN PRINCIPAL CITIES

YARWAY **BLOW-OFF VALVES**

Keeping up with the Kilowatts

PACIFIC BOILER FEED PUMPS FOR ELECTRIC UTILITY SERVICE

▲ Two Typical Pacific Boiler Feed Pump Installations ▼



ADDED SINCE 1950 BY:

ALABAMA POWER *Company*
ATLANTIC CITY ELECTRIC *Company*
CALIFORNIA ELECTRIC POWER *Company*
CENTRAL ILLINOIS ELECTRIC & GAS *Company*
CENTRAL ILLINOIS PUBLIC SERVICE *Company*
CINCINNATI GAS & ELECTRIC *Company*
COLUMBUS & SOUTHERN OHIO ELECTRIC *Company*
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ONE OF THE DESIGNERS AND BUILDERS

PACIFIC®

PACIFIC PUMPS INC.
HUNTINGTON PARK, CALIFORNIA
Offices in All Principal cities
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BF-24

Dairyland Power Cooperative, Wisc.
The Franklin Heating Station,
Rochester, Minn.
Kansas City Power and Light Co.
Missouri Public Service Co.
Montana-Dakota Utilities Co.
Pacific Gas & Electric Co.

Central Illinois Public Service Co.
Commonwealth Edison Company
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NATIONWIDE!

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Mohawk Station, Tulsa, Okla.
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*Central Stations and Utilities use... Graver Deaerating Heaters**

A partial listing of tray and spray-tray type installations with capacities up to 2,250,000 lbs. per hour.

* WRITE FOR MANUAL OF POWER PLANT INFORMATION

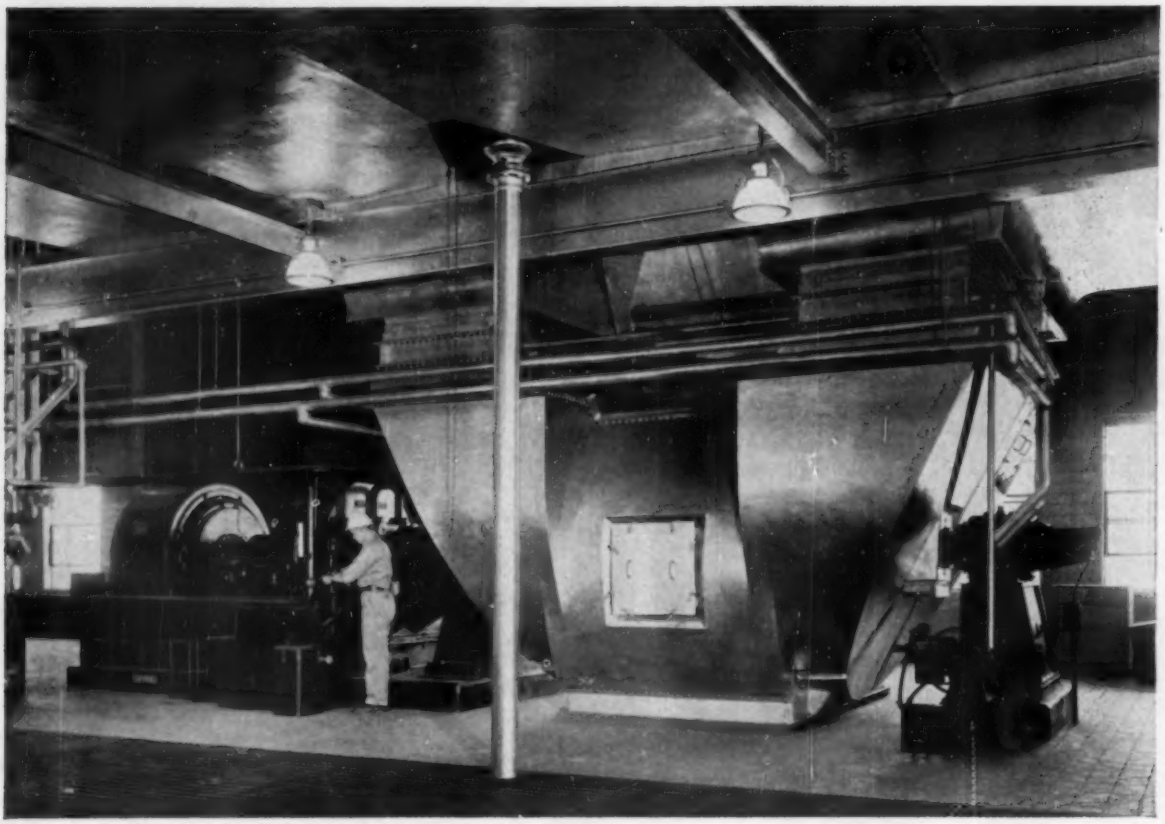
A COMPLETE LINE OF WATER TREATMENT EQUIPMENT

GRAVER

Industrial Dept.: I-212

GRAVER WATER CONDITIONING CO.
Division of Graver Tank & Mfg. Co., Inc.
216 West 14th Street, New York 11, N. Y.

American Blower Mechanical Draft

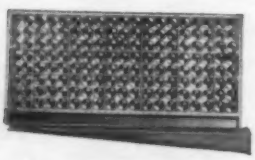


American Blower Induced Draft Fans meet the rigid requirements of modern power plants, where maximum pounds of steam are constantly produced at peak efficiency. Here are a few of the many features they offer:

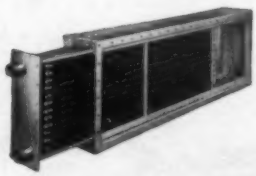
- High static efficiency, low R.P.M.
- Minimum boiler "outage"
- Certified ratings, minimum maintenance
- Minimum space requirements

To meet your exact specifications and ensure reliable performance, American Blower mechanical draft equipment is accurately formed and welded, fan rotors are perfectly balanced and tested, and all final assemblies are minutely inspected.

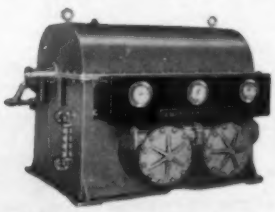
Other American Blower Heavy-Duty Equipment for Power Plant Applications



Collectors and precipitators for dust and fly ash control

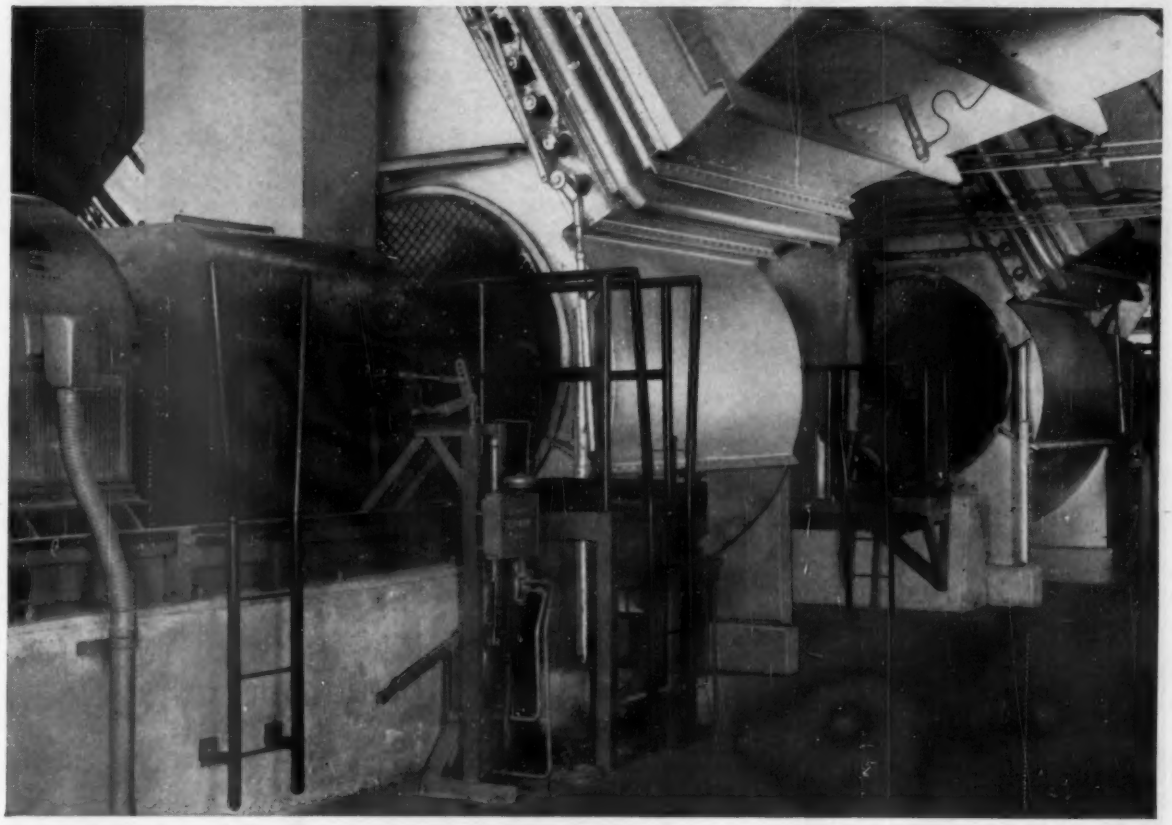


Heavy-duty steam coils for high-pressure duty



Gyrol Fluid Drives for boiler feed pump and fan control

Fans meet peak-efficiency standards



American Blower Forced Draft Fans are suitable for either indoor or outdoor installations. Each type of fan is carefully developed and its performance-rating guaranteed. Here are some of the reasons why American Blower Forced Draft Fans are widely accepted by power plants throughout the nation:

- Certified ratings
- Heavy reinforced housings and wheel-shaft assembly designed with first critical well above maximum operating speed
- Special streamline inlets designed for all wheel types to obtain high efficiency
- Choice of bearings to fit any application

If your plans include mechanical draft equipment—for new installations or as replacements—consult your American Blower sales engineer. He can give you helpful information on job-fitted American Blower equipment to meet your power plant requirements. Call our nearest branch office or write: American Blower Corporation, Detroit 32, Michigan. In Canada, look for Canadian Sirocco products.

AMERICAN BLOWER

Division of American-Standard

"BUFFALO" TYPE "CR" RADIAL BLADE FAN

VENTILATING AIR CLEANING AIR TEMPERING INDUCED DRAFT

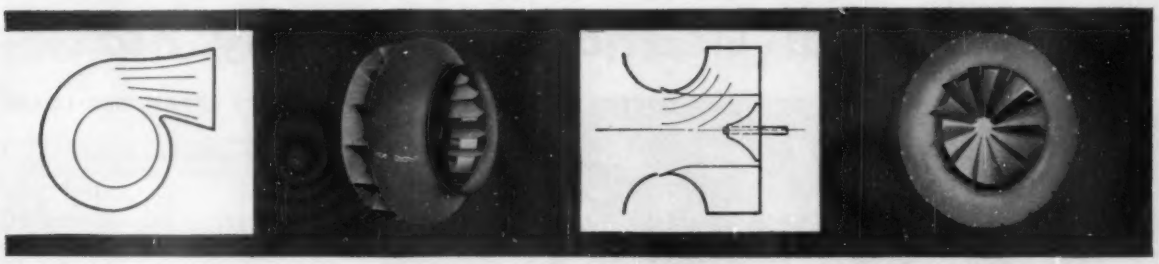
Engineered for high volume-high pressure service

Already proving its overall economy in stoker-fired induced draft, cement plant and other heavy-duty industrial service, this newest "Buffalo" Fan has the following advantages:

- **HIGH** Mechanical Efficiency — above 78% over a wide range.
- **DESIGNED** for high dust loading conditions.
- **LOWER** First Cost, when its high pressure, high capacity characteristics mean a smaller fan for the job.

Ilustrated here are the features that contribute to this desirable balance of efficiency and resistance to abrasion — the streamlined housing with diverging outlet — the new radial wheel with its deep, smoothly curved inlet flange mating with the inlet bell to form a true half-circle entry into the wheel. The wheel blades are radial at the tip, curving smoothly forward at the inlet. Further, "Buffalo" CR Fans are designed for use with an open inlet or with the highly efficient "Buffalo" variable inlet vanes shown.

WRITE FOR BULLETIN FD 205 and check the "Q" Factor* features that will give you the greatest all-around satisfaction and economy with this quality fan.



STREAMLINED HOUSING and diverging outlet aid efficiency, reduce abrasive effect.

TYPE "CR" RADIAL WHEEL — note how mating flanges of inlet bell and wheel flange form a true half-circle entry path with no flat sections or irregularities.

ACCURATE VOLUME CONTROL without reducing fan performance is obtained with "Buffalo" cantilevered variable inlet vanes set well into inlet bell throat.

**The "Q" Factor — the built-in Quality which provides trouble-free satisfaction and long life.*

BUFFALO FORGE COMPANY

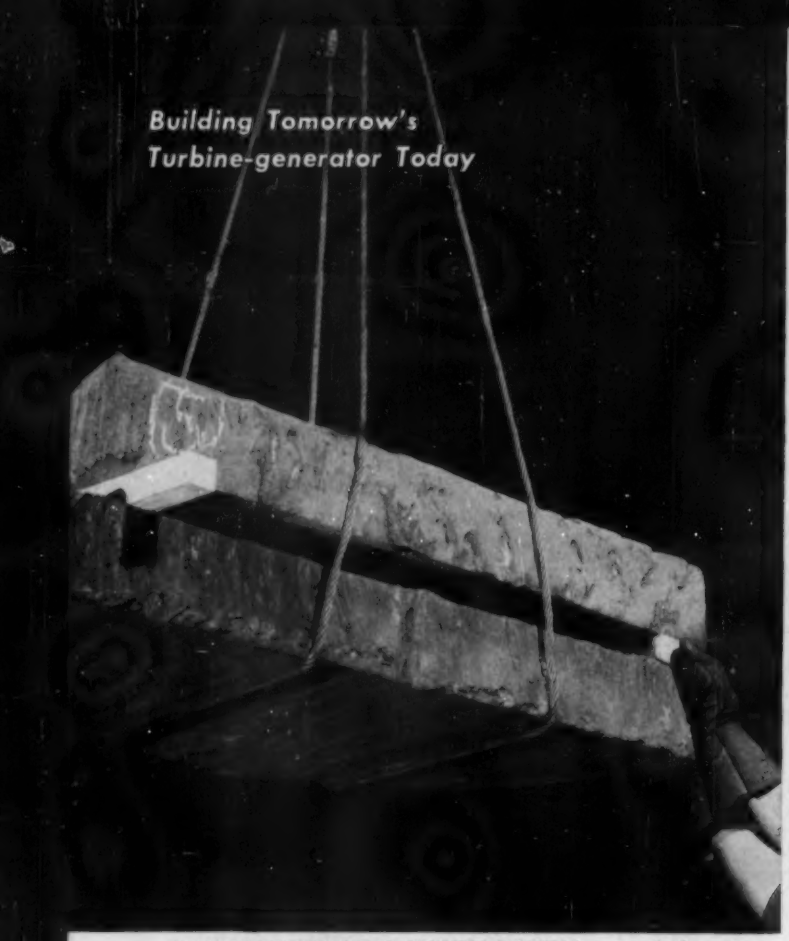
BUFFALO, NEW YORK

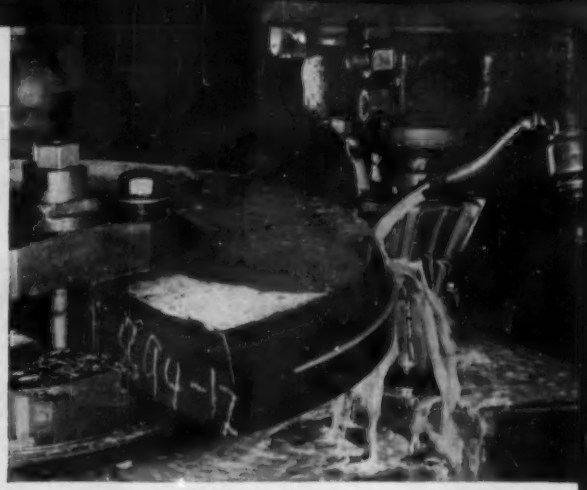
Canadian Blower & Forge Co., Ltd., Kitchener, Ont.

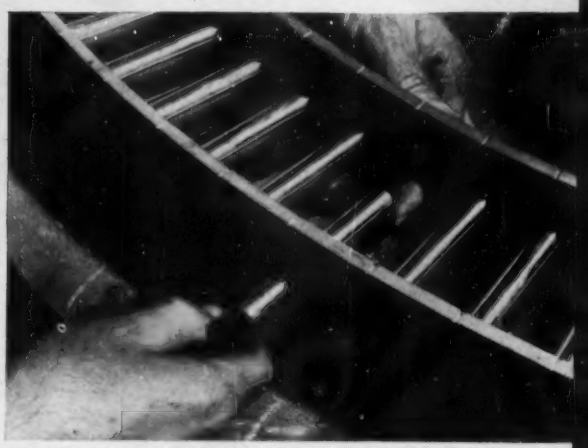
"Buffalo"

EXHAUSTING FORCED DRAFT COOLING HEATING PRESSURE BLOWING

Building Tomorrow's
Turbine-generator Today







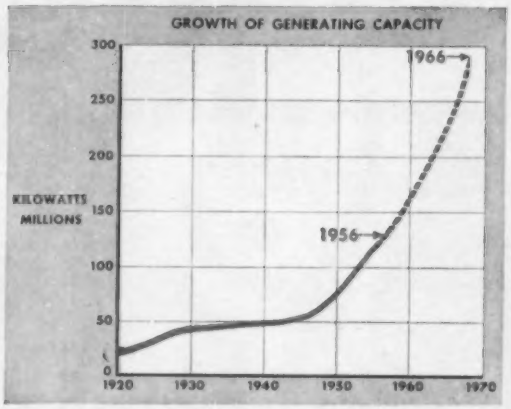
THE HIGH-PRESSURE END DIAPHRAGM WEBS are made from heavy alloy steel plates or castings. Some are ten inches thick and can withstand high pressure drops and maintain close clearances.

THE WEB is then carefully machined for welding (top). Nozzle partitions are machined from solid chrome-iron alloy and assembled in punched bands (bottom).

How General Electric builds sturdy nozzle-

GENERAL ELECTRIC MAINTAINS a continuing program of research on turbine diaphragms. This smoke tunnel provides a visual indication of how steam flow will follow new nozzle designs.

TO MEET TOMORROW'S EXPANDING LOADS



G.E. works with electric utilities and consulting engineers in these vital turbine-generator areas:

BASIC RESEARCH

APPLIED RESEARCH

PRODUCT DEVELOPMENT: NOZZLE-DIAPHRAGMS

TESTING

MAINTENANCE

THIS NOZZLE assembly is welded to the web and outer ring (top). A finishing operation puts a high polish on the partitions for a smooth steam path (bottom).

DIAPHRAGM HALVES are lowered into the turbine shell. The rotor is then assembled and the upper shell containing the top half of the diaphragm is added to form a series of complete compartments.

diaphragms to reduce turbine maintenance

TOUGH CONSTRUCTION HELPS PROTECT STEAM PATH AGAINST DESTRUCTIVE FOREIGN MATERIALS

Internal damage to the steam path can be a costly and time consuming cause of turbine shutdown. Should large amounts of foreign material enter the steam path whole rows of buckets and partitions might be severely damaged. This could mean a long and costly outage.

TO HELP GUARD against a long outage, General Electric builds turbine nozzle-diaphragms of tough, sturdy construction. And here's how they help. Should foreign materials enter the steam path, these rugged nozzle-diaphragms "compartmentalize" damage to a small area. This greatly simplifies bucket repairs or replacement.

GENERAL ELECTRIC MANUFACTURES these diaphragms from solid castings or plates carefully machined to shape. Nozzle partitions are machined from solid chrome-iron alloy and welded to, or cast integral with, the webs. These partitions must direct the steam flow at the proper angle and velocity to the adjacent buckets.

In this and many other areas of research G.E. is working with electric utilities and consulting engineering firms to design the power makers for tomorrow's load growth. For more information on General Electric turbines write for GER-905, Large Steam Turbine-Generator Department, General Electric Company, Schenectady 5, N. Y. 234-40

Progress Is Our Most Important Product

GENERAL ELECTRIC

LOOK TO THE ALLIS-CHALMERS TRACTOR SHOVEL LINE TO . . .

Match your coal-handling

If you're looking for big-capacity coal-handling ability, mobility and wide-range versatility—at low cost—the tractor shovel you need is in the Allis-Chalmers line.

First — advanced-design features make Allis-Chalmers tractor shovels the most productive and widely accepted in the field. Second — each unit offers a shovel that's a built-in part of the tractor — not just an attachment. Third — you have a choice of four sizes to match your requirements most efficiently.

You can increase Allis-Chalmers tractor shovel usefulness even more by replacing the bucket with a variety of quick-change attachments such as dozer blade, rock fork, rock bucket or lift tongs.

On every job, your Allis-Chalmers tractor shovel provides important advantages for you and your operator:

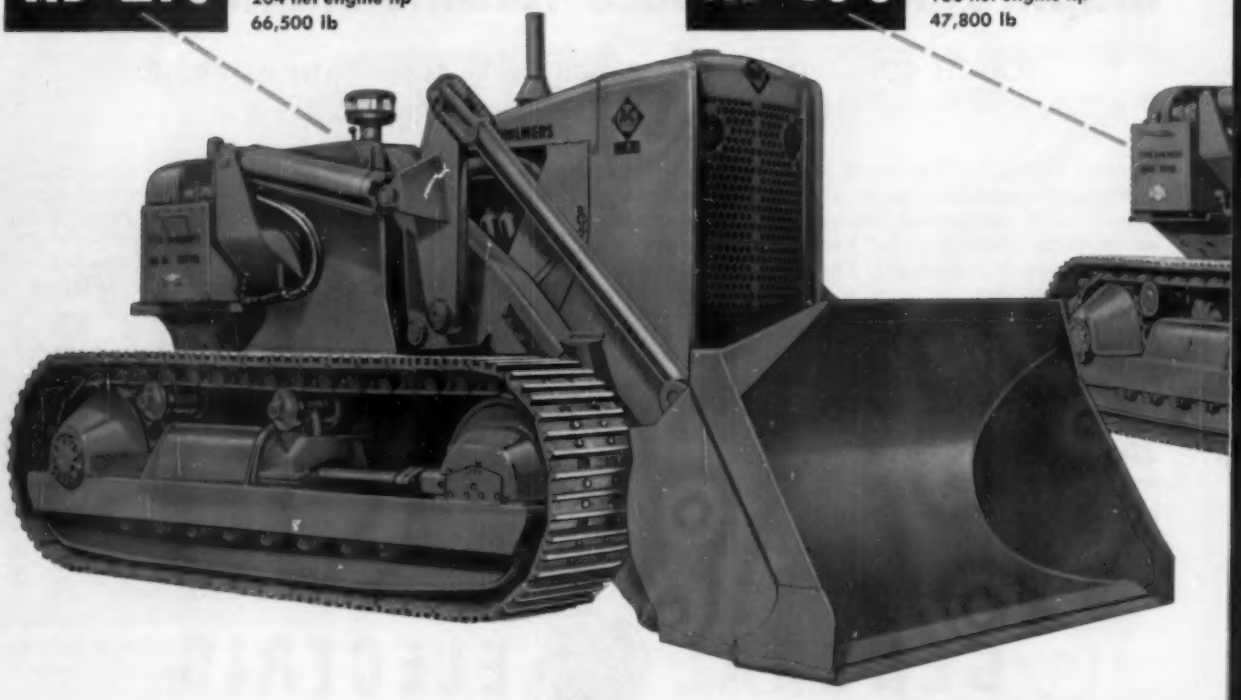
- Superior balance and low center of gravity
- Sure-footed stability with extra long track
- Greater strength with heavy welded-steel shovel side frames and low stabilizer
- Bucket design that makes loading and dumping fast, clean and easy
- Simplified hydraulics with 3-way, full-flow filtering
- Powerful, long-life Allis-Chalmers diesel engine
- All-steel main frame and one-piece final drive and steering clutch housing
- Timesaving service simplicity
- Heavy-duty roller bearing truck wheels
- 1,000-hour lube intervals on truck wheels, idlers and support rollers
- Better visibility, comfortable seats, and easy operating, accessible controls

HD-21G

Torque converter drive
7-yd (5.3-ton) capacity coal bucket
4-yd (3.0-ton) capacity standard bucket (shown)
13-ft, 4-in. dump height
204 net engine hp
66,500 lb

HD-16G

Torque converter drive
5½-yd (4.1-ton) capacity coal bucket
3-yd (2.2-ton) capacity standard bucket (shown)
12-ft, 3-in. dump height
150 net engine hp
47,800 lb



needs

HD-6G

2¼-yd (1.7-ton) capacity coal bucket
1½-yd (1.1-ton) capacity standard bucket (shown)
10-ft dump height
57 net engine hp
19,600 lb

HD-11G

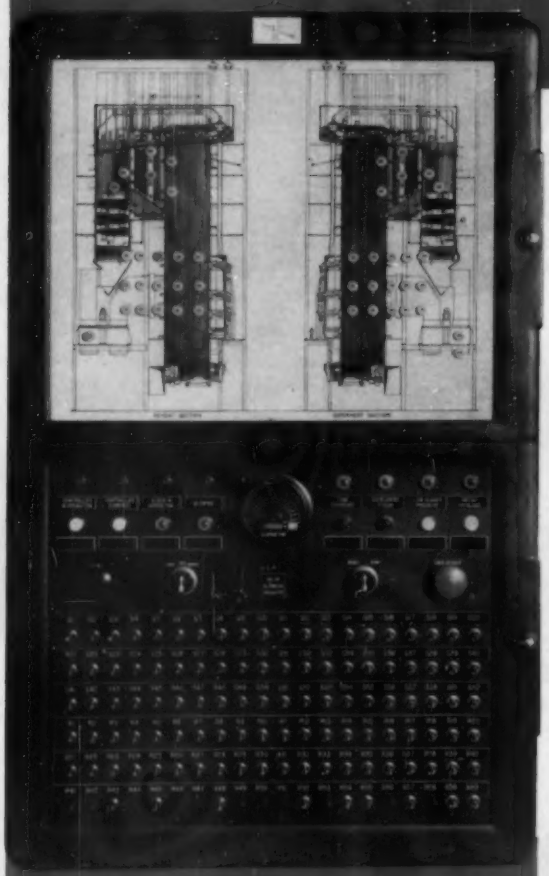
3¾-yd (2.8-ton) capacity coal bucket
2¼-yd (1.7-ton) capacity standard bucket (shown)
11-ft, 7-in. dump height
105 net engine hp
32,000 lb

Ask your Allis-Chalmers Construction Machinery dealer for the complete tractor shovel story and for a look at one of these great tractor shovels at work. And remember, your dealer is headquarters for factory-trained servicemen, factory-approved facilities and complete stocks of True Original Parts.

ALLIS-CHALMERS, CONSTRUCTION MACHINERY DIVISION
MILWAUKEE 1, WISCONSIN

ALLIS-CHALMERS

It's Vulcan Selective Sequence for Astoria Station's 2,400,000 lb./hr. Boiler!



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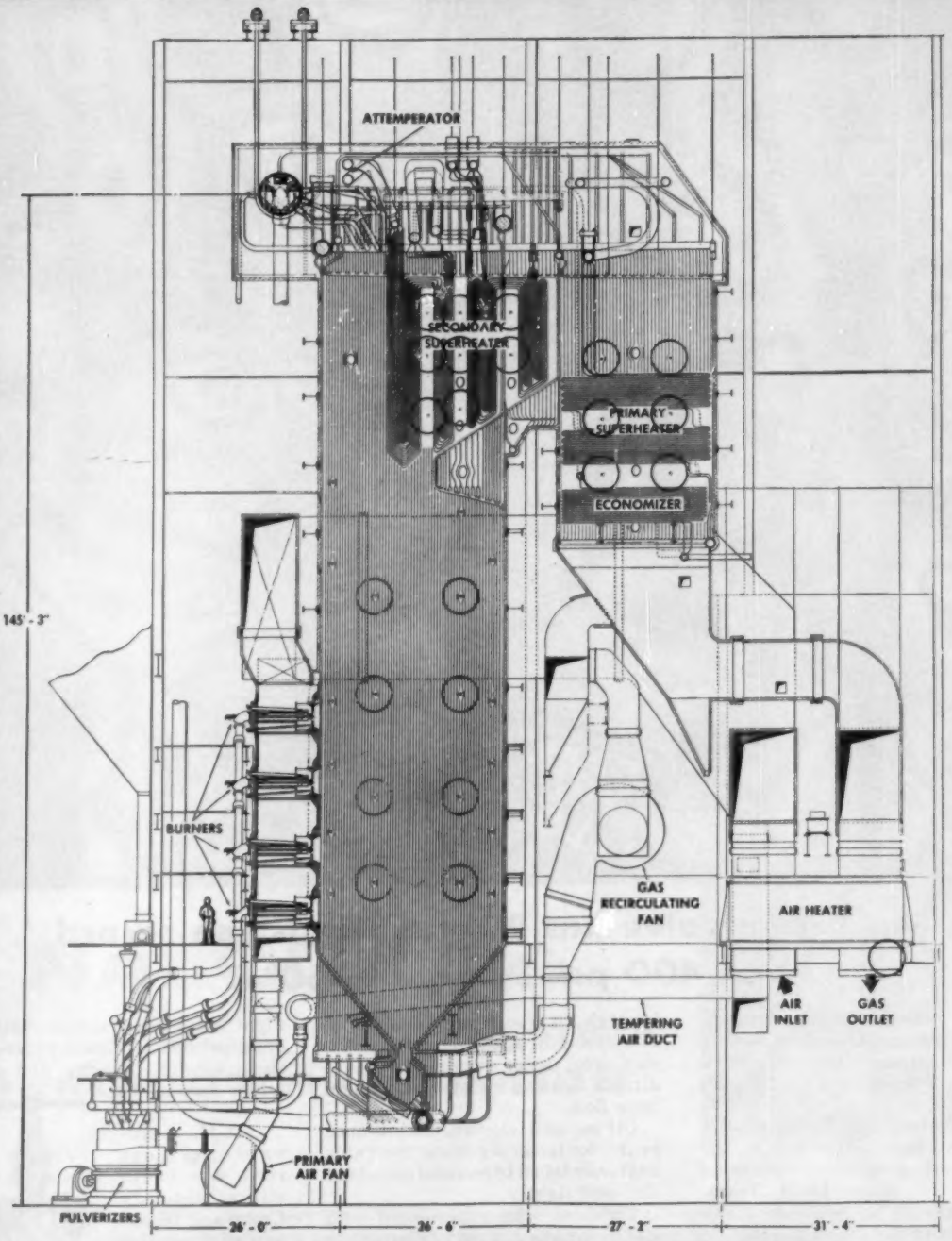

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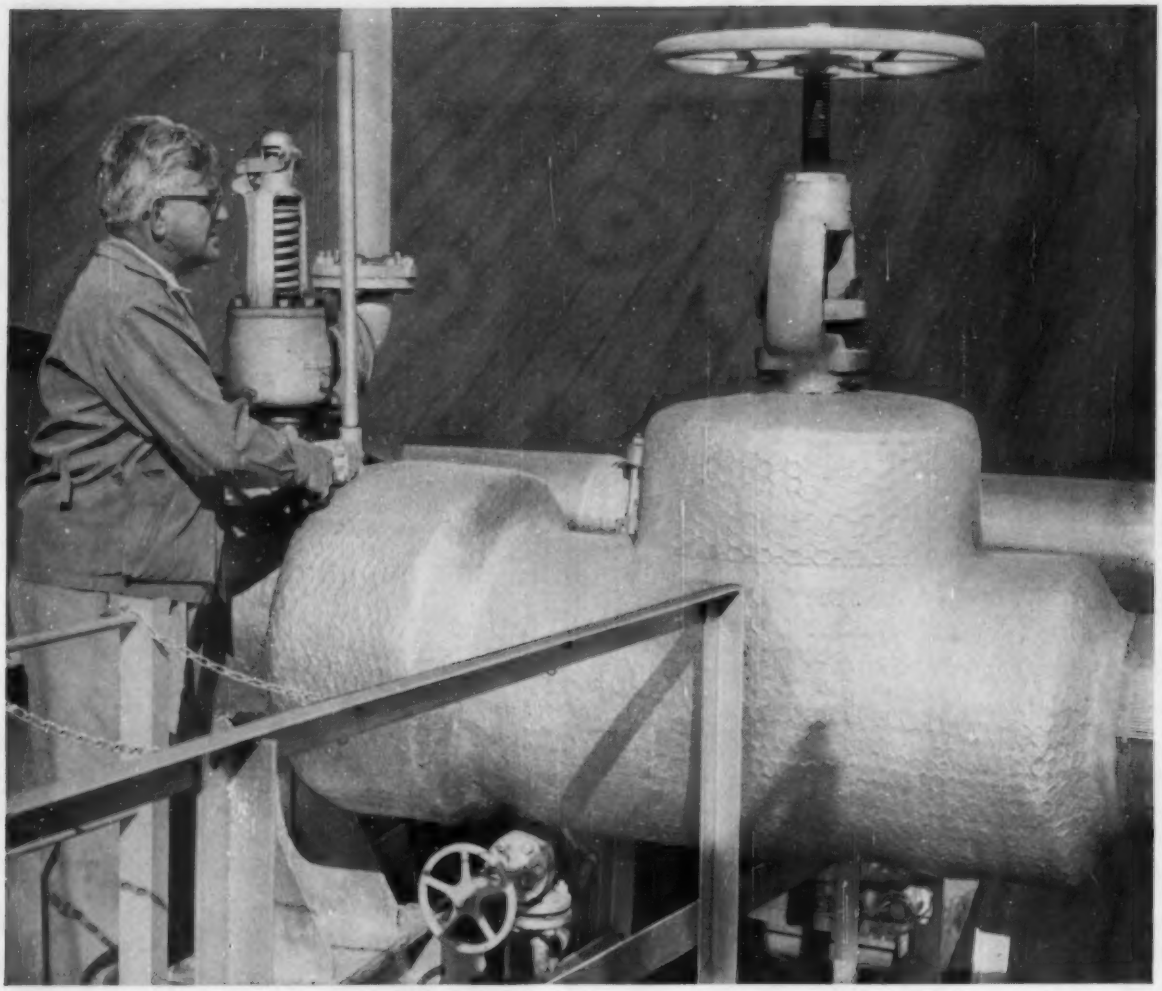
Design Pressure, PSI.....2,500 High Pressure Steam Temperature, F..1,050

Reheat Steam Temperature, F.....1,000



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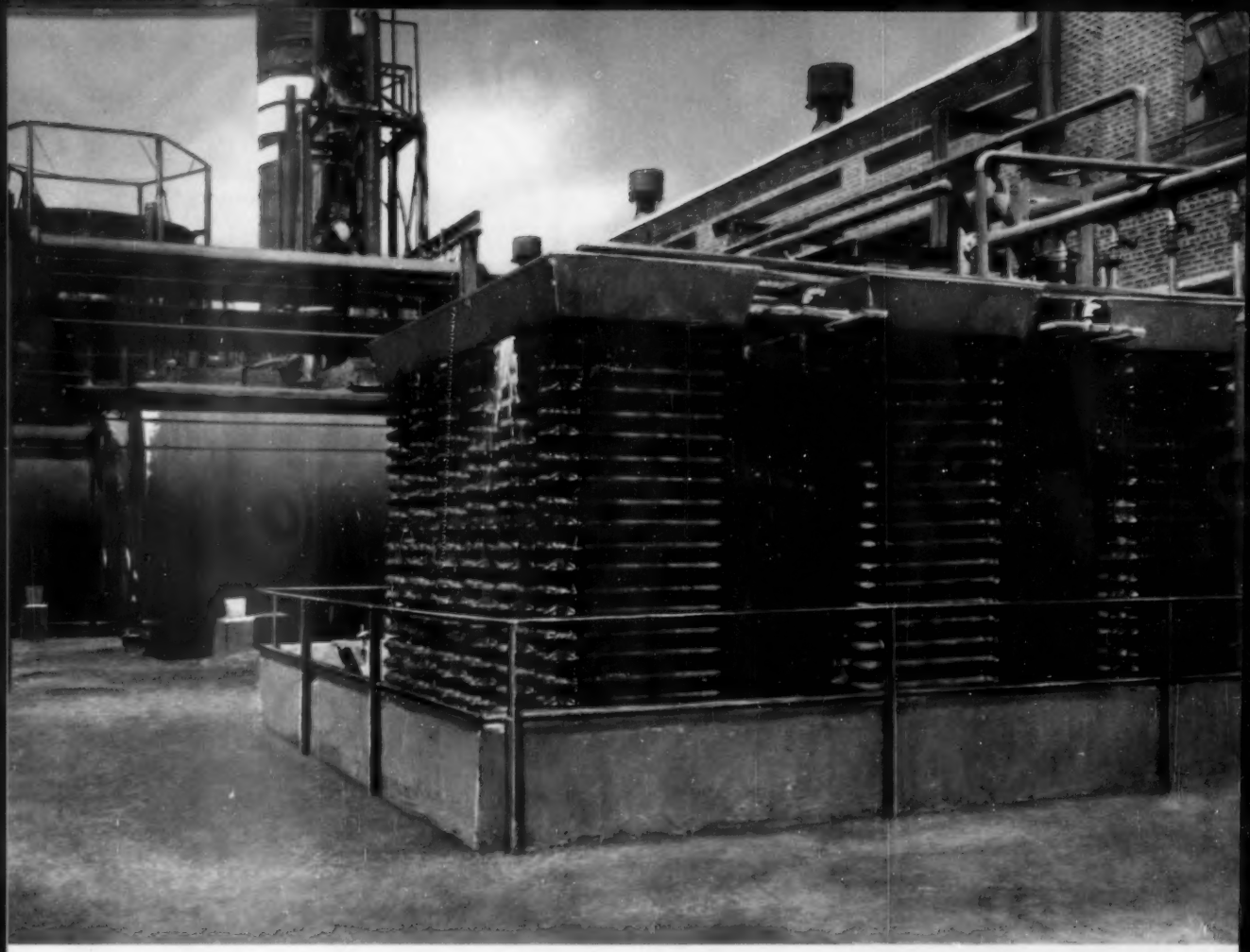

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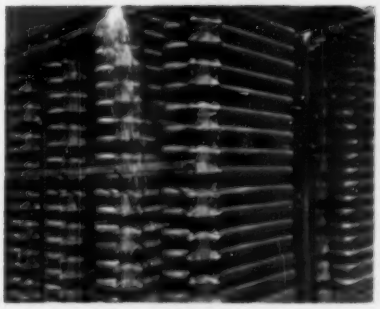

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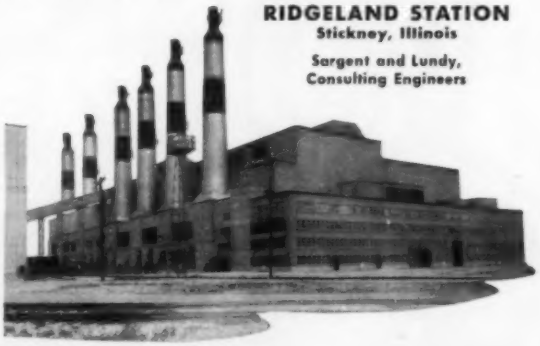

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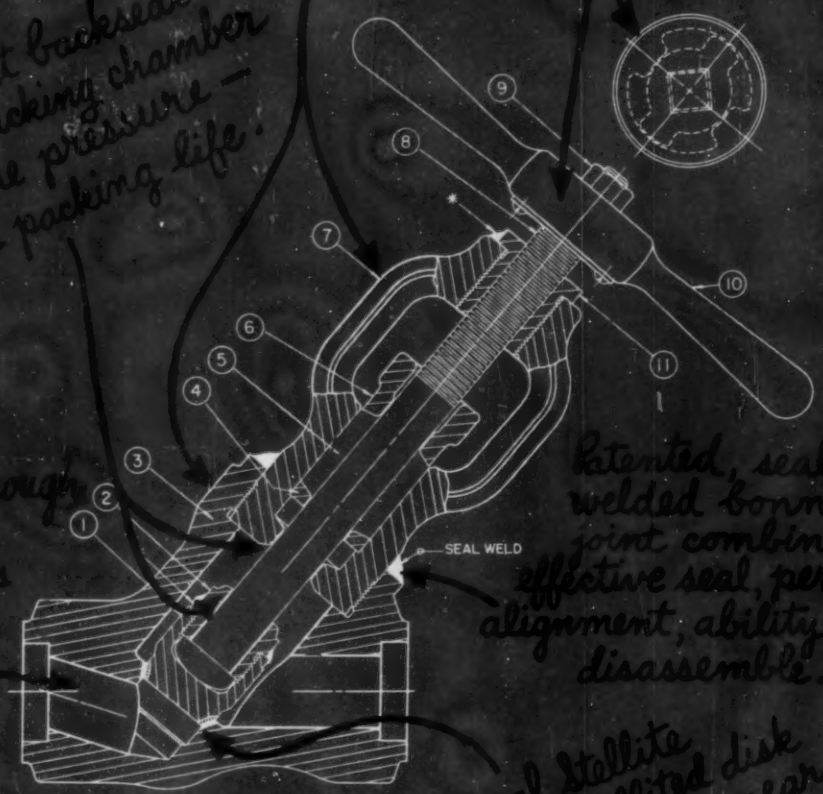

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WHERE A.S.T.M. SPECIFICATIONS ARE INDICATED THE LATEST REVISION APPLIES

PIECE NO.	NAME OF PIECE	NO. REQ'D.	MATERIAL	SPECIFICATIONS	EDWARD M'S NO.
1	DISK	1	FORGED STEEL	A.S.T.M.A182 GRADE F11	227
2	DISK NUT	1	EVALLOY	A.S.T.M.A182 GRADE F6	212
3	BODY	1	FORGED ALLOY STEEL	A.S.T.M.A182 GRADE F11 (b)	227
				A.S.T.M.A182 GRADE F22 (c)	230
4	JUNK RING	1	STEEL, EVALIZED	A.I.S.I. C1020	23
5	PACKING RINGS		EVALPAK	HIGH TEMPERATURE PACKING	501
6	GLAND	1	FORGED STEEL	A.S.T.M.A105 GRADE II	111
7	BONNET	1	FORGED ALLOY STEEL	A.S.T.M.A182 GRADE F11 (b)	227
				A.S.T.M.A182 GRADE F22 (c)	230
8	STEM	1	EVALLOY	A.I.S.I. GRADE 416	261
9	STEM NUT	1	STEEL	A.S.T.M.A194 CLASS 1 OR 2	124
10	IMPACTOR HANDLE	1	MALLEABLE IRON	A.S.T.M.A47 GRADE 32510	322
11	YOKE BUSHING	1	BRONZE	A.S.T.M.B148 GRADE 9B HT	432
12	GLAND BOLT NUT	2	STEEL	A.S.T.M.A194 CLASS 1 OR 2	124
13	GLAND STUD	2	STEEL	A.S.T.M.A193 GRADE B7	208
14	GLAND BOLT LOCKNUTS	4	STEEL	A.S.T.M.A194 CLASS 1 OR 2	124

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FORGED STEEL UNIVALVES
GENERAL ASSEMBLY
FIG.-3924 SIZES ½, ¾, 1, 1¼, 1½, 2

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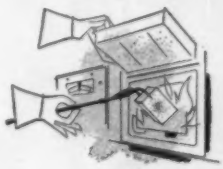

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2 Steam-Jet Ejectors, twin-element, two-stage with surface type inter- and after-condensers.

4 Vertical Condensate Pumps, each a three-stage unit rated 1400 gpm, 250 ft. head.

4 Horizontal Circulating Pumps, each a single-stage double-suction unit rated 41,000 gpm, 57 ft. head.

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FIG. 19003 WE—900-Pound Steel Pressure Seal Gate Valve.

FIG. 11365 WE—Steel Pressure Seal Horizontal Lift Check Valve for 1500 Pounds W.S.P.

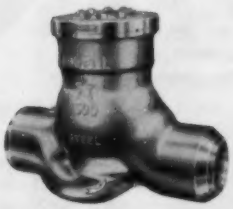

FIG. 3031 WE—Steel Globe Valve for 300 Pounds W.S.P.

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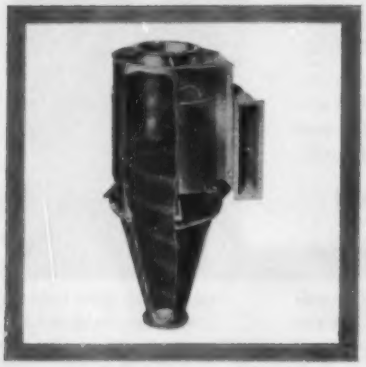

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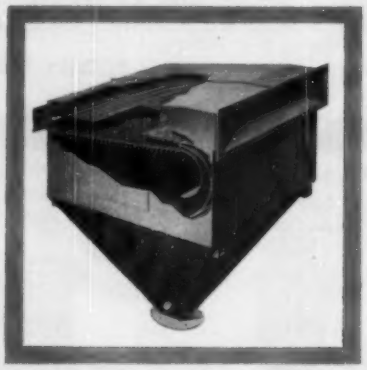

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Editorial

Pure Research and Its Rewards

The recently concluded Sixth International Symposium on Combustion held at Yale University, August 19–24, and reported in this issue, pp. 73, brought us into contact with a rather different form of meeting than we usually attend. The subjects discussed were somewhat remote from the ones currently absorbing the power generation field and the speakers were men of whose activities we know little or nothing. Yet we found this meeting extremely interesting.

The technical program offered some 116 papers with an additional ten to be published although not presented. The very fundamentals of flames, their formation, structure and propagation, were among the subjects of discussion. Much of the material was drawn from laboratory experiments or research projects still very much underway and the papers were frequently progress reports. But the opportunity of an exchange of ideas among fellow scientists and the dissemination of data from widely separated investigations make the Symposium a meeting of high importance to these combustion specialists.

The evidence of military-sponsored research was strong. As an example many of the efforts to fathom the properties of flames were prompted by the desire in military aeronautic circles to speed up new developments. It apparently is felt that the fundamentals of combustion, so important to air flight as we know it today, are only sketchily realized. Be that as it may the studies now being pushed in combustion laboratories throughout the world are certain to turn up information that may someday be of great value in the power generation field. One thing stands out. Fundamental research opens avenues of thought that would otherwise remain unknown except to some chance discovery. And today the demands for ever more energy superimposed upon the fight to hold down energy costs makes it unlikely that the power generation industry will permit manufacturers to rely upon such chance discoveries. We look to see a greater emphasis upon fundamental research within the power field than has been the case heretofore.

Power Engineering Behind the Iron Curtain

Many factors affect the availability of engineering information. Data may be withheld for varying periods of time in order to secure patent protection for new developments, and there are occasions when some presumed competitive or commercial advantage is the stated reason for delaying release of technical information. Most engineering editors do not look upon the withholding of information for the reasons just enumerated as denial of the freedom of the technical press, largely because the end result of an economy based on the free enterprise system is an acceleration of progress which makes even more information available for publication.

In the past two decades these traditional and long-established practices of withholding information have been far overshadowed by various systems of classifying technical information for reasons of national security. The totality of modern warfare and its direct relationship to discoveries and developments in pure science and applied technology are the obvious causes of these extensions of restricted information beyond the region of specific armaments data.

The Iron Curtain established by the Soviet Union following World War II represents by far the most complete and rigid control of information yet devised. In the field of steam plant design and operation, there have been a few pinholes, such as the Russian steam tables up to 1112 F, 4266 psia, which COMBUSTION published in March 1953, through a German source; and the papers delivered by members of the Soviet delegation to the 1955 International Conference on Peaceful Uses of Atomic Energy at Geneva. There have also been propaganda pronouncements from Moscow concerning sensational power projects (though details have been conspicuous by their absence), and a few Americans have visited the Soviet Union to take a look at production facilities, including power projects. Unfortunately the reports thus far presented by such visitors have taken on a flavor of sensationalism and do not tell the American power engineer what his Russian counterpart is doing.

This issue of COMBUSTION contains two technical papers selected from the nearly twenty presented by members of the Soviet delegation to the Fifth World Power Conference held in Vienna last June. We believe that they contain much original technical information in the area of the supercritical pressure steam cycle that is worthy of a place in the permanent engineering literature. We commend these papers to our readers as examples of straightforward technical writing in the classical style and as evidence of the engineering accomplishments of their opposite numbers from the other side of the now less opaque Iron Curtain.

Experimental Boiler Plant with Once-Through Boiler for Steam Conditions up to 4266 Psia, 1112 F*

By K. A. RAKOV, L. B. KROL, M. D. PANASENKO and N. V. BULGAKOVA

Heat Engineering Institute of U.S.S.R.

From 1946 to 1955 a great amount of work was done in the U.S.S.R. in the construction, operation and investigating of an experimental steam-generating plant for 4266 psia, 1112 F. The boiler went into operation in November 1949. Up to September 1955 the boiler had been in operation for 17,500 hr, 11,250 hr with pulverized coal of low volatile content and 6250 hr with fuel oil. Only one rupture of a tube of 15 XM steel and several cracks in welded joints of EI-257 steel were observed during this period. At present an additional plant for 300 metric tons per hr, 215 ata, 580 C (661,500 lb per hr, 3057 psia, 1076 F) is under construction at one of the thermal power stations in the U.S.S.R. Work has begun on designing a further high capacity, 300 ata, 650 C plant for one of the power stations near Moscow, and on a further plant with a boiler-turbine unit having a capacity of 300,000 kw and a steam pressure of 300 ata.

STUDIES on generation of steam at pressures up to 300 ata (4266 psia) and temperatures 600 C (1112 F) (2–4)[1] have proved the technical possibility of utilizing such steam at the turbine inlet with 15–16 per cent savings in fuel as compared with steam of 90 ata, 500 C (1280 psia, 932 F). As early as 1938 the Heat Engineering Institute of the U.S.S.R. decided to study and build an experimental steam-generating plant to investigate the production of "supercritical steam" (1).

Considerable research and development work carried out by various organizations in the U.S.S.R. as well as data on the operation of installed once-through boilers were of great help in designing the experimental supercritical steam-generating plant.

The experimental 300 atm, 600 C once-through "Ramsin" type steam boiler, with a furnace whose walls are cooled by horizontal tubes, was manufactured at the Podolsky Machine Works. Heating surface units, heaters and steam pipes which have to bear heat stresses greater than 530 C (986 F) are made of a new austenitic steel (EI-257) specially developed for this boiler.

The first 300 atm, 600 C, supercritical pressure steam-generating plant in the world was put into operation on Nov. 14, 1949. No difficulties were experienced in starting up the boiler. Minor defects in the feed pump equipped with hydraulic-type piston were caused by ruptures in the tubing and quick wear of the pump valves. These faults were eliminated by redesigning the valves and using the reserve pump.

Description of Experimental Plant

The plant consists of a once-through boiler with a steam-generating capacity of 12 metric tons per hr (26,450 lb per hr) test steam pipes, 102 × 17 mm. (4.02 × 0.67 in.) in diameter, two pressure-reducing installations (one for the auxiliary steam pipes used when starting up the boiler, and the other for the main piping), two piston-type feed pumps of 18 tons per hr capacity, and a delivery pressure up to 350 kg per sq cm (4977 psig), a feedwater pipeline, a bubbling-type deaerator, a balanced-type steam separator for starting up the boiler and other auxiliary equipment.

Feedwater with a temperature of 100 C (212 F) enters the upper radiating surface (a radiation economizer), after passing through an economizer, suspended tubes in the transition zone and a convective superheater (Fig. 1). By this time it is heated to 392 C (738 F).

After this, the water enters a transition zone located in the convective part of the boiler after the superheater. The water which has then a temperature of 412 C (774 F) enters a radiant superheater in the lower part of the furnace. Final superheating of the steam from 480 C (896 F) to 600 C (1112 F) is effected in a convective superheater. All the tubes of the heating surface are 32 × 6 mm (1.26 × 0.24 in.) in diameter. There are 12 circuits in the convective units, and 10 in the radiant ones.

The heating surfaces of the convective and radiant superheaters are made of EI-257 steel, and the remaining parts are of chromium-molybdenum 15 XM steel. The convective elements of the boiler were pre-assembled

* A paper presented by members of the Soviet delegation to the Fifth World Power Conference held in Vienna, Austria, June 17–23, 1956.

[1] Numbers refer to bibliography at end of paper.

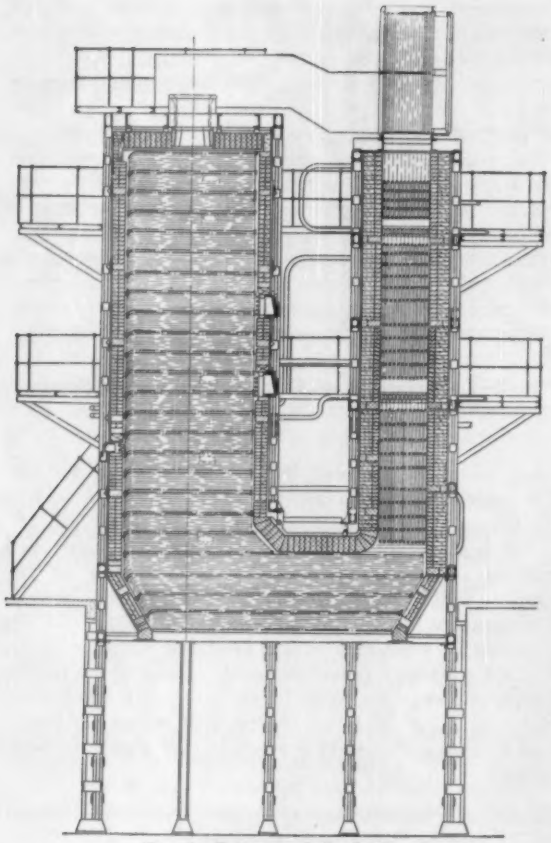


Fig. 1—Section of the boiler

in blocks by contact butt welding, while the radiant elements were assembled on the site by gas welding. The butt joint welds of 15XM steel were annealed at temperatures of 920–940 C (1688–1724 F) in special muffles. Annealing was controlled by a recording instrument. The butt joint welds of EI-257 steel were not annealed.

When starting up, water and steam flow in the starting steam piping and enter the starting separator. The starting steam piping is equipped with a remote-controlled motor-driven stop valve, an oil-controlled throttle, and an uncontrolled throttling device consisting of eight orifice discs for critical pressure drops. A pressure reduction of the steam-water mixture to 1–2 atm, in these throttling units insures noiseless starting of the boiler and quiet operation of the separator. After the steam is heated to 500–530 C (932–986 F) it flows to the main steam piping where an oil-controlled throttle is installed, automatically keeping pressure at the required level at the boiler outlet. After passing the throttle and steam cooler the steam flows to a turbine in the adjacent thermal power station under a pressure of 1849–2133 psig and 940 F.

The hydraulic piston feed pumps operate at a water temperature of 100 C (212 F). The pumps are equipped with Leonard drives which permit synchronized water and fuel supply. The feed pipeline 70 × 13 mm (2.75 × 0.51 in.) in diameter is made of "10" steel.

The boiler is designed for firing pulverized coal with low volatile content and mazout (residual fuel oil). The pulverized coal comes from two mills of an adjacent boiler and passes to an intermediate bunker. Screw-conveyors coupled to d-c motors then transport the coal to a turbulent burner with adjustable blades mounted on the furnace top.

Results of Boiler Operation

From November, 1949, to March, 1952, the boiler operated on fuel oil; afterwards it burned pulverized coal with low volatile content. To reduce heat absorption when operating the boiler on fuel oil, the tubing in the upper radiant part was insulated with a 10–15 mm (0.4–0.6 in.) gunite coating first up to a height of 1 meter and subsequently to 2 meters.

The performance of the boiler was carefully watched and controlled throughout its operation. Samples from heating surface tubes and steam pipes were periodically cut out to determine the condition of the metal. Corrosion phenomena as well as the performance of different methods of welding were examined on special pieces of tubes welded into the tube system of the boiler.

In 1950 and 1951 several failures occurred in the connecting piping of the feed pumps. Valves and spindles in the throttle units and fine fittings gave some trouble because of rapid wear. During a hydraulic test after 1000 hr of boiler operation, cracks were discovered in 6 welded copper bosses used to mount thermocouples on the superheater tabes made of EI-257 steel. Two cases of steam leakage in the welded seams of steam pipes were also discovered. These pipes were not used any more. Continuous plant operation of 625 hr and later of 900 hr was already achieved in 1950.

In 1952 a considerable number of minor defects occurred in the drainage and the small diameter end-sections of the steam pipes where low temperatures occur. This is explained by the fact that EI-257 steel is not stabilized and is subject to intercrystalline corrosion in the presence of electrolytes. A ring crack occurred in the weld seam of a 102 × 17 mm (4.02 × 0.67 in.) diam tube, which was apparently due to excessive stresses caused by the way in which the steam pipes were suspended.

No difficulties were encountered in converting the boiler to pulverized-coal firing in 1952. Screw conveyors driven by d-c motors and connected to a potentiometer control insured fuel supply with an accuracy up to 1 per cent. This permitted a temperature regulation in the steam superheater within a range of 5 to 10 deg C (9 to 18 deg F).

At the end of 1952 a number of cracks in welded tubes of EI-257 steel occurred during experiments in which various salts were added to the boiler water in order to investigate the effects of salt deposits. Damaged butt welds were located at the end of the radiant and the beginning of the convective superheaters as well as in the steam pipes. Crack formation was due to corrosion caused by the salt contents of the steam (stress corrosion). During the next three years of boiler operation, no such troubles occurred.

During the period 1953–Sept. 15, 1955 the boiler, fired with pulverized coal, was in operation for 9900 hrs, being shut down only 22 times. In this period external cracks were discovered on sharp bends of EI-257 steel tubes at the end of the radiant superheater. One rupture occurred on the highest tube of the upper

radiation section. The tube was of 15 XM steel. Contact-welded seams on heating surfaces of 15 XM and EI-257 steel as well as gas-welded seams on 15 XM steel tubes have shown no defects during the entire period of boiler operation.

The experimental plant for supercritical steam pressures of the All-Union Heat Engineering Institute has been working during the past 6 years at pressures of 230–300 ata (3271–4266 psia), 540–600 C (1004–1112 F) for about 17,500 hr, of which 11,250 hr have been on pulverized coal with low volatile content, and 6250 hr on fuel oil. Out of the 113 shutdowns of the boiler, 11.5 per cent were caused by defects in boiler tubes and steam piping, 8 per cent by troubles occurring in the feed pumps (at the beginning of operation); the remaining shutdowns were either planned or caused by troubles in the auxiliary equipment.

The average time of continuous operation of the boiler increased from year to year. In 1954 planned shutdowns of the boiler amounted to 75 per cent and in 1955 to 72 per cent of total shutdowns.

Boiler Operating Conditions

To prevent uneven distribution of the steam-water mixture forming at subcritical pressures, the boiler is started up at a supercritical pressure with the help of oil-controlled and uncontrolled throttles. As the water is heated the resistance of washers in the uncontrolled throttle increases and the boiler operator slowly opens the controlled-oil throttle from a remote control board. At a steam temperature of 550 C (1022 F) the process of starting is over and the boiler is connected to the operating steam pipeline within 10–20 sec. The speed of temperature rise at the boiler outlet is usually 10 deg C (18 deg F) per min, the starting time to 550 C being 45 min. Fuel oil is used in starting. This speed was not increased to avoid heavy temperature stresses. The above method of starting the boiler was used more than 120 times without any difficulties arising. No large temperature differences and no pulsation phenomena in the boiler element were observed.

The boiler can be shut down according to two methods. In the first method, fuel supply is stopped and water is pumped through to cool the coil pipes rapidly and to wash away the salts precipitated in the boiler. In method two, water and fuel supply are cut off simultaneously; water and steam remaining in the boiler are drained off.

The second method is more advantageous as it causes less wear and was adopted oftener than the first one. For short interruptions only the "Stop" switch was used and steam and water were not drained off.

Generally the boiler operated with a constant load of 12 metric tons per hr (26,450 lb per hr) when burning pulverized coal and 10 to 12 metric tons per hr with fuel oil.

As a rule, feedwater supply was constant. Only when abrupt changes in steam pressure occurred did the ratio between feedwater supply and steam generation become irregular for a short time. Changing steam generating capacity was easily achieved by changing feed pump speed. Up to 1953 steam pressure of the boiler was regulated by an oil-operated remote control device and later on, by an automatic pressure control. For steady boiler loads, pressure was maintained constant within 1 per cent by a hand-operated throttle. The same result was achieved under changing load with the help of an automatic control.

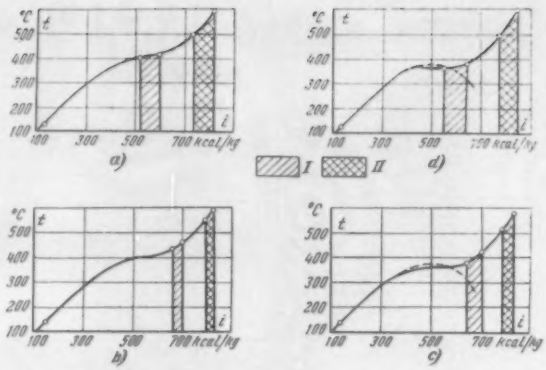


Fig. 2—I—Transition zone. II—Convective superheater
(a) Test No. 2 (b) Test No. 5 (c) Test No. 8 (d) Test No. 9

Temperature of superheated steam was controlled, without injection, by changing either water or fuel supply which work under a synchronized system. Temperature was maintained constant within ±5 deg C (9 deg F) when fuel oil was fired and within ±10 deg C (18 deg F) with pulverized coal. Cases of fluctuating temperatures in the superheater were rare when firing fuel oil. They were more frequent when pulverized coal was used as fuel in a single-burner highly screened furnace.

Results of Investigations of Boiler Operation at Supercritical Pressures

The heat capacity of water or steam is very great under supercritical pressures in the saturation zone (in the following this zone will be called "phase transition zone"). As a result a considerable increase in heat content causes only a small temperature rise in either water or steam.

The exactness of measurements is increased by using 300 atm siphon differential-pressure gages for the measuring of small pressure drops in the boiler elements and by using multiple thermocouples for measuring of temperature differences (8). Siphon differential pressure gages register pressure drops in boiler tubes caused by flow resistances up to 360 mm (14.2 in.) w.g.

Measurements have shown that the temperature of steam-water in the boiler elements changes considerably when the boiler load is reduced from 100 per cent to 50 per cent at a constant superheat temperature of 600 C. due to the increasing amount of heat absorbed by radiation. Thus, water and steam temperatures in the upper radiant part, the phase transition zone, and the radiant superheater increase by 40–50 deg C (72–90 deg F).

The temperature of water after the radiant economizer, and of steam-water in the transition zone increases by 40–60 deg C (72–108 deg F) and of steam after the radiant superheater by 20–50 deg C (36–90 deg F) with a pressure rise of 180 to 300 ata (2560–4266 psia) and a constant superheat steam temperature of 600 C (1112 F). Changing boiler operating conditions at constant terminal temperature of superheated steam causes a shifting of the phase transition zone. When increasing

the load or reducing superheated steam temperature this zone will shift toward the boiler outlet in the direction of the steam flow; when reducing the load or increasing superheat, this zone will shift toward the boiler inlet (Fig. 2).

Under supercritical steam pressures the zone of transfer of water into superheated steam shifts into a zone with lower heat content in relation to high subcritical pressures. This increases the heat content (Δi) in radiant and convective superheaters, and decreases Δi in the zone of preliminary heating and steam formation. In supercritical pressure boilers a considerable heat increase of steam or water reduces temperature differences at the end of different boiler elements.

The temperature of the steam was measured at the outlet of every circuit of heating surfaces in the boiler, with the exception of the convective economizer, where great variations in the temperature of the steam were not to be expected.

On the basis of numerous tests carried out with boilers operating on fuel oil and pulverized coal with low volatile content, it was ascertained that the temperature of the steam or water in different circuits was almost the same. At pressures of 180 to 300 ata, temperature deviation from average value in the circuits of the upper radiant part was from 2 to 6 deg C (4–11 deg F). At supercritical pressures the minimum temperature difference occurs at 220–230 ata (3128–3271 psia), that is in the zone of maximum heat capacity. In a boiling zone located in the upper radiation part the temperature differences were also not considerable at 180 ata (2560 psia). In the transition zone, and at the same pressure, temperature deviations of steam-water also did not exceed 2 to 6 deg C (Fig. 3). When the boiler was fired with fuel oil, at pressures ranging from 180 to 250

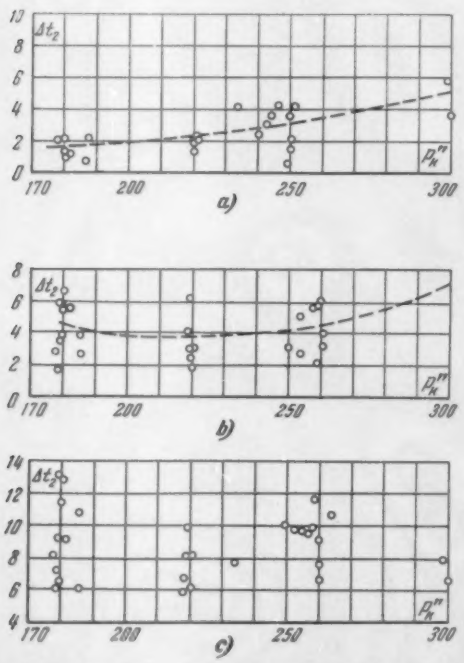


Fig. 3—t-i Diagram: Temperature differences in parallel tubes

(*a*) Upper radiant part (*b*) Transition zone (*c*) Convective superheater

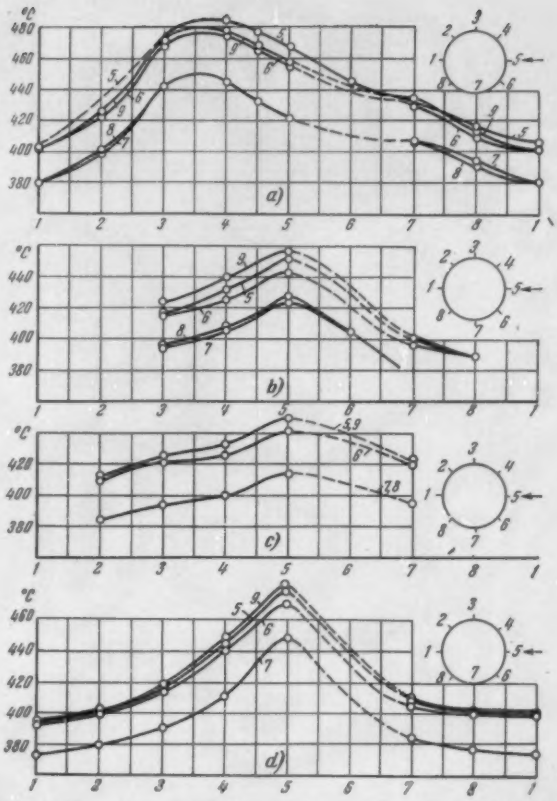


Fig. 4—Curves for metal temperatures along the perimeter of a tube in the upper radiant part

(*a*) Section I (*c*) Section III
(*b*) Section II (*d*) Section IV

ata, the difference between steam temperatures in different circuits installed after the convective superheater dropped from 6–13 deg C (11–23 deg F) to 6–8 deg C (11–14 deg F). When fired with pulverized coal, a rise in temperature differences up to 30–40 deg C (54–72 deg F) was observed. This was due to fouled tubes and to 200–250 per cent rise of heat content increase in the convective superheater

Measurements of the difference between the temperature on the outer surface of tubes in the convective superheater and the transition zone, and the temperature of the steam showed that the difference did not exceed 10 to 35 deg C (18 to 63 deg F) at a boiler output of 12 metric tons per hr and a specific thermal load 10^3 kcal per sq m per hr, (q = 12–14).

Temperature of tube walls was measured on four cross-sections of the two top tubes in the upper radiant part near the arch.

The temperature curves for the eight measuring points in the measured cross sections are shown in Fig. 4. These curves are the result of 53 measurements at pressures ranging between 180 to 300 ata (2560–4266 psia), and loads of 6 to 12 metric tons per hr. At cross-section 1, located about 200 mm (7.9 in.) from the arch (and therefore exposed to considerable heat radiation from the arch), the maximum metal temperature was measured at point "4" which has an angle of 45 deg to horizontal. In cross-sections 2–4 exposed to symmetrical radiation, the maximum temperature was registered for the frontal parts. The metal temperature

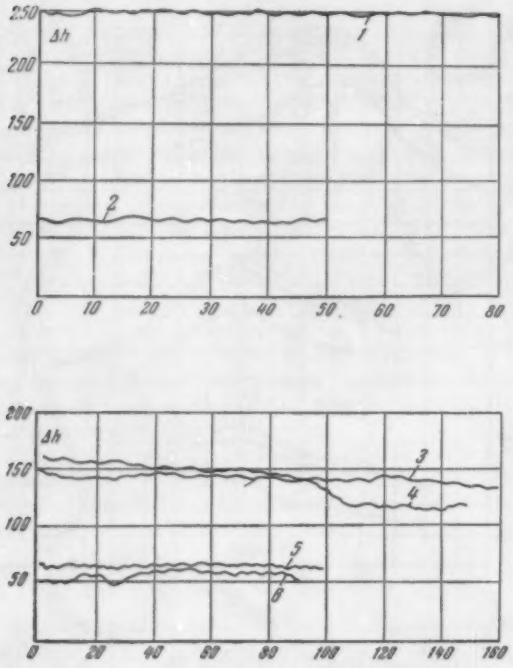


Fig. 5—Starting and stopping the boiler, Δh mm w.g., p = 300 atm, t° = 590–595 C

Circuit No. 1—D = 12.4 t/h
Circuit No. 1—D = 6.6 t/h
Circuits Nos. 3, 4—D = 12 t/h
Circuits Nos. 5, 6—D = 6.6 t/h

exceeded the temperature of the steam by 40–50 deg C (72–90 deg F) on the back and by 107–115 deg C (193–207 deg F) on the front. Thermal loads on the front points reached 200—250·10³ kcal per sq m per hr. The temperatures at the front and rear points dropped with greater loads due to a decrease in temperature of the steam in the end of the upper radiant part. The highest temperatures (up to 530 C = [986 F] on the front side) were observed for a boiler load of 6 metric tons per hr and a pressure of 260–300 ata, when steam temperatures reached 410–415 C (770–779 F). The temperatures on the rear side reached 440–480 C (824–896 F) in this case.

The metal temperature at 300 ata (4266 psia) was higher than at 180 ata (2560 psia). However, in all cases tube wall temperatures did not exceed permissible values for pearlite steels, in spite of the fact that the tubes were located near the heart of the flame (distance about 1 meter).

The measurements also enable determination of temperature differences between the top and the bottom of the tubes and to clearly establish the influence of steam conditions thereon. At supercritical pressures this difference did not exceed 3 to 8 deg C (5.4 to 14.4 deg F) independent of the boiler load. At a pressure of 180 ata and a load of 6–7 metric tons per hr, superheat conditions were attained at the end of the upper radiant part, and temperature differences between the top and bottom of the tubes did not exceed 5–6 deg C. Under an increase of load up to 11–12 metric tons per hr, a water-steam mixture appeared at the end of the upper radiant part, separation of water and steam took place in the horizontal tube.

The velocity of the steam-water flow in different tubes was measured under pressures ranging from 180 to 300 ata and under constant loads of 6 to 12 metric tons per hr and under varying loads. Starting and stopping conditions of the boiler were also investigated, the speed of the recorder ribbon being 1 and 2 mm/sec (Fig. 5). No pulsation of steam water in the coils was observed under all operational conditions, neither when firing with oil nor when pulverized coal was used as fuel.

Deviations from uniform distribution of water in the tubes did not exceed 10 to 15 per cent. Throttle orifices (5 mm diam) were installed in the tube inlets of upper radiant part. Measurements of dynamic pressures taken after removing the orifices showed that the hydrodynamic characteristics of flow in the tubes remained stable, and no pulsation occurred. For a steam-water mixture, deviation from uniform distribution rose to ±20 per cent (in respect to average consumption) in the transition zone at pressures of 180 to 190 ata.

The complete resistance of the boiler at 300 ata, 600 C (4266 psia, 1132 F), under a load of 12 tons per hr was 11.8 atm (168 psi) when burning oil, and 9.3 atm (132 psi) when burning pulverized coal, that is, 3.9 per cent and 3.1 per cent of the steam pressure respectively. The decrease in resistance of the boiler when firing pulverized coal (from 7.4 to 4.9 atm) is explained by an increase in convective heat exchange and a decrease in the length of the section where steam is superheated.

At a pressure of 190 ata (2702 psia) and a final superheat temperature of 600 C, boiler resistance under a load of 12 metric tons per hr rose to 15 atm (213 psi), that is, to 7.9 per cent of the boiler outlet pressure, due to larger specific volumes and velocities of the steam. Under same steam conditions boiler resistance did not corre-

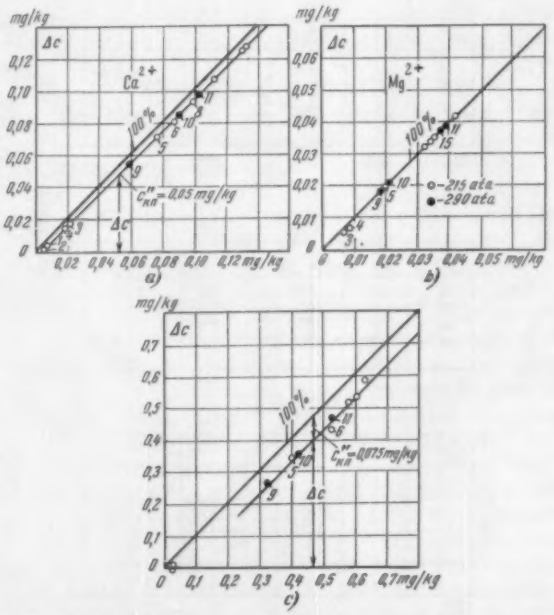


Fig. 6—Relation between deposits of Ca and Mg ions and corrected sulfate residue in the boiler and their content in the feedwater

(*a*) Ca^{2+} deposit (*b*) Mg^{2+} deposit (*c*) Sulfate deposit

spond to the square of the boiler load, because the phase transfer zone shifts.

Feedwater for the experimental boiler was usually a condensate with a salt content of 0.1 to 0.5 mg per kg. Experiments in 1950 and 1951 showed that when feedwater had impurities amounting to 0.2 to 0.5 mg per kg, about 80 to 90 per cent of these impurities (generally they had a high degree of solubility) were carried away with the steam; calcium compounds settled in a larger degree than sodium compounds.

In 1955 a new series of experiments (from 30 to 50 hr) were carried out at pressures of 215 to 300 atm to study salt depositing in the boiler. The condensate feed water had a salt content of about 0.3–0.7 mg per kg. Calcium and magnesium salts were added in quantities imitating leakage of cooling water into the condensers. These experiments showed that calcium salts are almost completely deposited in the boiler. The content of Ca^{+2} ions in superheated steam was 0.005 mg per kg (Fig. 6), independent of pressure and their concentration in the feedwater. Magnesium salts were also deposited in the boiler and not carried away in the steam; small concentrations of sodium salts leave practically no deposits.

Salts are deposited over a rather wide region at the end of the economizer zone. However, nearly no deposits settled from the end of the phase transfer zone on. Salt content in steam flowing to a turbine must not exceed 0.05 mg. per kg (0.05 ppm) to ensure a long time of turbine operation without the necessity for scouring. The permissible salt content in feedwater is determined by the content of sodium salts which pass completely through the boiler, as well as by the permissible content of calcium salts, keeping in view that the boiler must function reliably even if they settle on heating surfaces. As the permissible value for salt deposits increases when the transition zone is located in the range of moderate heat loads, it is advisable to shift the transition zone to the convective section of the boiler.

The extremely high demands on quality of feedwater and steam, as well as the impossibility of extracting salt deposits from once-through boilers for supercritical pressures, necessitate the utmost reduction of impurities and the development of methods for extracting salt deposits from the cycle of a power station. It is necessary to reduce the loss of condensate water in the power station cycle as much as possible, and to use tightly sealed condensers. Leakage of cooling water must not exceed 0.001 per cent of the steam entering the condenser. The salt content in makeup water flowing into the cycle from evaporators and salt-extracting units should not exceed 0.05 mg per kg (0.05 ppm).

Tests on control characteristics of the boiler were made at pressures of 250, 170 and 130 ata and under changing operating conditions. These investigations have shown that the experimental boiler responds slowly to changes in operational conditions. The temperature at the boiler outlet lags by 2.5 to 3 min behind the change while the speed of temperature rise of the steam does not exceed 7.5 to 10 deg C per min (13.5–18 deg F per min). The total transient period lasts 15 to 25 min. There remains therefore sufficient time to take regulating measures. Studies to ascertain where impulses for regulation are best to be placed have shown that the temperatures beyond the upper radiant part and the transition zone are the quickest to change. Therefore, it is most advisable to use these temperatures for boiler control after enlarging the impulses of the highly sensitive thermocouples. Tests have proved that sudden changes in feedwater and fuel supply, causing a shift of the phase transition zone, and a change in the water and steam capacity of the boiler result in a temporary increase or decrease of steam output, which influences the steam temperature at the boiler outlet.

Investigations have shown that automatic control for a supercritical, once-through steam generator with high evaporating capacity, is not more difficult than for a subcritical steam generator. The accuracy with which the temperatures of steam-water can be regulated, increases due to an increase in heat capacity of the superheated steam, provided that the accuracy of fuel feed remains constant. A constant temperature of superheated steam can be obtained by means of spraying or without it.

Steam fittings of forged austenitic steel (EJ-ITC) with inner diameters of 3 to 68 mm (0.12 to 3.65 in.) were installed in the experimental plant. The use of forged fittings was completely justified since no cracks occurred in the casings and covers of the fittings, despite the fact that a number of sudden steam temperature rises occurred. Steam leakage and welding seam troubles were experienced very rarely. The flanged covers of the valves held by bolts of chromium-molybdenum-tungsten alloy steel are tightly sealed; no steam leakage was observed. At first, soft asbestos gaskets in nickel-foil covers were used; later on they were replaced by corrugated EJ-IT steel gaskets.

Flake graphite has been successfully used for gland packing in valves operating at a temperature of 600 C (1112 F). As a rule, the stuffing boxes of the fittings remained steam-tight. Small and medium diameter steam pipes remained tight and no steam escaped through the fittings.

However, the functioning of the internal parts of valves was not satisfactory. In a number of cases the tight fit of the valves deteriorated after being opened and closed several times. The sealing parts of the drain valves also wore out rather quickly. Weight-type safety valves for 300 ata, 600 C as well as water fittings for 350 ata, 100 C have functioned satisfactorily.

BIBLIOGRAPHY

(1) K. A. Rakov, "Project of the VTI Experimental Plant for Maximum Water-Steam Pressures of 300 atm., 600C." *Teplo i Sila*, 1938.

(2) K. A. Rakov, "Prospects for the Application of Supercritical Steam," collected works of the Academy of Sciences of the U.S.S.R., 1938.

(3) K. A. Rakov, "Prospects for the Application of Water Steam at Critical and Supercritical Pressures," collected works "The Use of Steam with High Parameters," 1941.

(4) K. A. Rakov, "Application of Water Steam at Supercritical Pressures," papers of the Session on Boiler Construction, 1948.

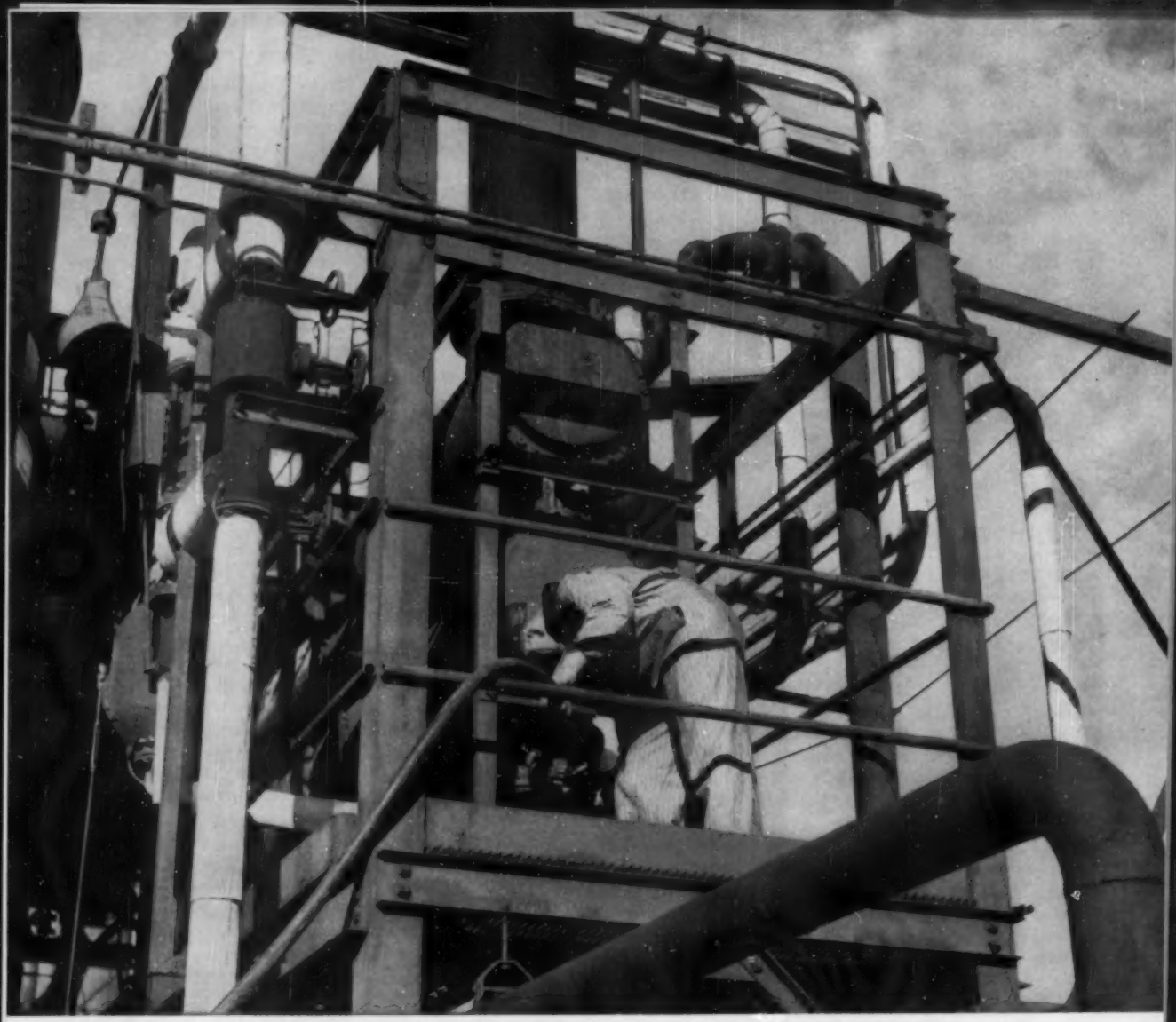
(5) K. A. Rakov, "Once-Through Steam Generators," edited by Ramsin, 1948.

(6) K. A. Rakov, E. N. Krasotkin and M. A. Bulgakova, "High Pressure Differential Manometer for Heavy Pressure Drops," *Izvestija* VTI, 1950.

(7) A. P. Nemov, J. M. Lstrovsky, "Some Conclusions on the Topic of Putting Supercritical Steam Generators into Operation and Mastering Them," *Teploenergetika*, No. 9 (1955).

(8) M. A. Styrikovich, "Methods of Salt Extraction in Supercritical Steam Pressure Plants," *Teploenergetica*, No. 1 (1955).

(9) U. M. Kostrikin, A. I. Filimonov, "Extraction of Salts and Silicic Acid from the Steam-Water Cycle by Means of Turbine Blow-Down," *Teploenergetica*, No. 1 (1955).



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Working Process of Super-High-Pressure Once-Through Boilers*

By M. A. STYRIKOVICH

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This paper shows that at pressures above 2275 psia once-through boiler working processes change greatly, especially with respect to heat exchange from heating surfaces to the working substance and the behavior of the solids contained in feedwater. The range of flow velocity, dryness factor and heat flux, within which stable nucleate boiling occurs, greatly decreases on nearing the critical pressure. With increased pressure the solubility of a number of substances in steam grows, determining steam contamination of once-through boilers. At a pressure up to 2844 psia effective extraction of salts from the cycle and reduction of the requirements as to feedwater may be achieved by means of separators. At higher pressures it is necessary to limit the salts entering the cycle in every way and to use various methods for the extraction of salts from the cycle.

RECENT years have been marked by a significant rise in the initial steam conditions in the steam-power cycle. High-capacity boilers for steam pressures of about 170–180 ata (2420–2560 psia) at superheater outlet are already in operation in the U.S.S.R. and other countries; high-capacity once-through boilers for a steam pressure at superheater outlet of 215 ata (3060 psia) are manufactured, and an experimental full-size supercritical pressure steam boiler for a pressure of 300 ata (4266 psia) has been operating in the U.S.S.R. for several years. High-capacity supercritical pressure steam boilers with pressures of 300 to 350 ata (4266–5000 psia) are being designed in the U.S.A.

Steam generation at pressures of 170–300 ata (2420–4266 psia), i.e., in the region near the critical pressure, shows some characteristic features which are discussed in this paper. Once-through boilers are mainly dealt with because they are the most promising steam generators for the given range of pressures; furthermore, only this type of steam generators may be practically used at a pressure above 200 ata (2844 psia).

The working processes in conventional boilers discussed in this paper are also important for nuclear reactors cooled with water under high pressure.

Reliable operation of a steam generator within a wide range of operational conditions depends upon a perfect organization of heat exchange especially when the temperature of tube inner surfaces is near that of the working substance, even at the highest heat flux which practically occurs. In pulverized coal-fired steam generators of high capacity the local values of the heat flux do not exceed $(0.3–0.4) \times 10^6$ kcal per sq m hr (61,500–82,000 Btu per sq ft hr). Only in the liquid fuel-fired boilers do they reach the value of 0.5×10^6 kcal per sq m hr (102,500 Btu per sq ft hr).

The most intensively heated radiant heating surfaces in the conventional boilers are, as a rule, cooled by boiling water flowing through the tubes. The nucleate evaporation is maintained steady in the steam generators at a pressure not exceeding 140 ata (2000 psia) at a heat flux of about 0.5×10^6 kcal per sq m hr, and even higher. In this case the temperature difference between the wall and the boiling liquid increases very slowly with the rise of the heat flux and even at its highest value does not exceed 5–10 deg C (9–18 deg F). This means that the variation of temperature difference is practically negligible. These conditions are maintained even at the moderate weight velocities of the steam-water mixture, for instance 200–300 kg per sq m sec, until the dryness factor of mixture "x" exceeds 0.9–0.95.

Disturbances in normal conditions of heat exchange occur only under very exceptional operating conditions. In the steam generators of once-through boilers they usually occur at the phase separation of the water-steam mixture in horizontal or slightly inclined steam-generating tubes. Overheating of the tube top surface which takes place in this case and its dependence upon various factors have been extensively investigated for a wide pressure range (up to 210–215 ata $\cong$ 3000–3060 psia) (1, 2).[1] The phase separation may be avoided by the

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[1] Numbers refer to bibliography at end of paper.

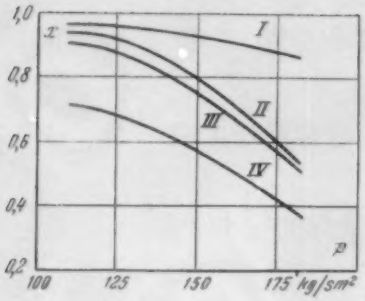

Fig. 1—Dryness factor corresponding to Δt = 50 C (90 F) in dependence upon pressure and heat flux at G_0 = 200 kg/mm²/sec

I. q = (230–260) × 10^3 kcal/sq m hr
II. q = (475–500) × 10^3 kcal/sq m hr
III. q = 600 × 10^3 kcal/sq m hr
IV. q = (700–750) × 10^3 kcal/sq m hr

selection of sufficient weight velocities or by an increase of the tube inclination angle.

The experimental investigations of recent years (6, 16) have, however, shown that the range of the dryness factor, the velocity of the steam-water mixture and the heat flux in vertical tubes, within which the nucleate boiling is maintained, decreases with pressure rise. It is especially noticeable near the critical pressure. The value of the heat flux at which the transition to film evaporation takes place depends upon pressure, weight velocity and dryness factor. At the present time this dependence can be calculated neither analytically nor with the help of the similarity theory, for this dependence is based on the experimental data under natural conditions.

There are no satisfactory methods to summarize the experimental data for heat transfer from wall at temperatures above the boiling point to liquid at temperatures below this point (so-called surface boiling). Also for slightly superheated super-high pressure steam, the use of the common dimensionless dependence is hampered by a very great difference in the physical properties of the steam near the wall and the steam in the turbulent core of the flow (for instance, P_r of wall = 2.5 at the P_r of the flow = 20). This does not make reliable even the method of summarization, in which the variations in fluid properties along the radius are taken into consideration (3, 4).

The experiments carried out in the *ENIN*,[2] part of which have been recently published (5, 6, 16), cover a rather wider ange of pressures (up to 230 ata = 3270 psia) and enthalpy from subcooled liquid to slightly superheated steam. The value of heat flux in the greatest part of the experiments varied in the region typical for conventional steam generators, (0.2–0.8) × 10^6 kcal per sq m hr. These experiments have shown that normal temperature conditions within the range of the heat flux ($q \leqslant 0.5 \times 10^6$ kcal per sq m hr) are maintained at 140 ata (2000 psia) up to a dryness factor (by weight)—X = 0.8–0.9 even at low weight velocity—G_0 = 200 kg per sq m sec (Fig. 1).

A deterioration in the heat exchange is, however, observed at 185 ata (2630 psia) within the whole range of $X \geqslant 0.5$ (at the same values of q and G_0). Thus, poorer conditions of heat exchange of the water walls located near the flame core with usual heat flux and at the pressure of 185 ata may be observed within a wide range of the steam contents and weight velocities.

At heat flux ranging from 0.2 × 10^6 to 0.5 × 10^6 kcal per sq m hr and at low weight velocities of the flow ($G_0 \leqq 500$ kg per sq m sec) the disturbance in nucleate boiling results in a sudden increase of the temperature of the tube wall which may bring about a rapid destruction of the tube. At high weight velocities, no sudden change in temperature takes place, but a gradual rise of the wall temperature which occurs with the increase of the mixture's steam contents. Moreover, the greater the weight velocity, the less the increase of wall temperature.

Therefore, at such pressures one should either avoid such high steam content (drum boilers) and expect the wall temperature to be near the boiling temperature, until low weight velocities of the flow set in, or maintain high weight velocities of the flow (once-through boilers). In this case the wall-flow temperature difference (Δt) depends upon the heat flux value and the selected weight velocity.

One cannot expect nucleate boiling to be maintained within the whole range of the dryness factor beginning with the boiling point at subcritical pressures ($P \geqslant$ 200 ata = 2844 psia). For instance, at G_0 = 450 kg per sq m sec the transition to the worse conditions of heat exchange is observed in the zone of beginning of evaporation (x = 0) at a pressure of 200 ata (2844 psia) and q_{cr} = 0.55 × 10^6 kcal per sq m hr; at a pressure of

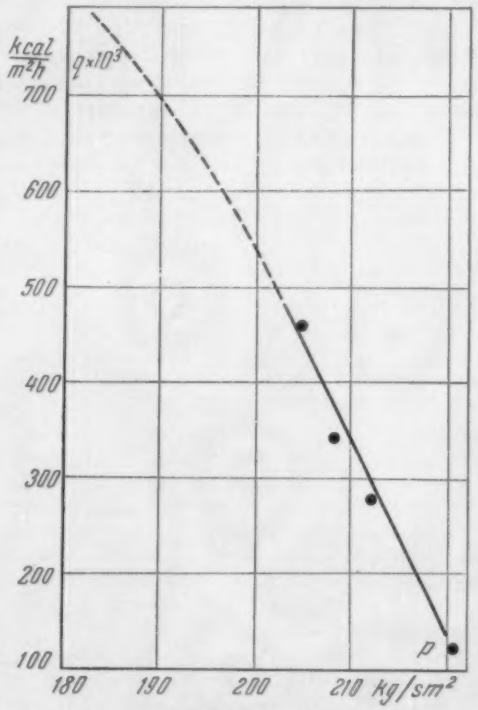

Fig. 2—Dependence of critical heat flux (q_{cr}) on pressure (P) near boiling point at weight velocity of about 430 kg per sq m sec

[2] Institute of Energetics of the Academy of Sciences of the U.S.S.R.

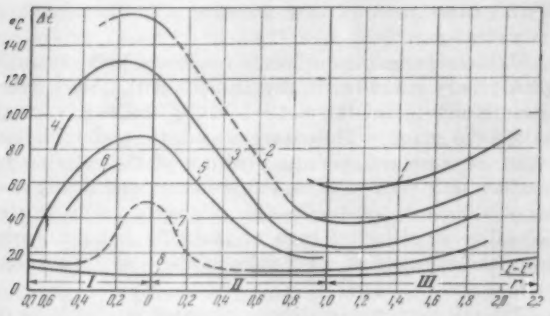

Fig. 3—Dependence of temperature difference of tube wall and substance upon increment of enthalpy and weight velocity of substance (G_0) at q = 270,000 kcal per sq m hr and pressure about 220 kg per sq cm (3128 psi)

1. G_0 = 390 kg per sq m sec
2. G_0 = 440 kg per sq m sec
3. G_0 = 480 kg per sq m sec
4. G_0 = 500 kg per sq m sec
5. G_0 = 500 kg per sq m sec
6. G_0 = 600 kg per sq m sec
7. G_0 = 785 kg per sq m sec
8. G_0 = 1650 kg per sq m sec

210 ata (3000 psia) q_{cr} drops to 0.35 × 10^6 kcal per sq m hr and at a pressure of 220 ata (3130 psia) even to 0.13 × 10^6 kcal per sq m hr (Fig. 2). Therefore, one should take into consideration those conditions of heat exchange for the whole zone of evaporation at a pressure of $P \geqslant 200$ ata at which it is necessary to maintain high weight velocities of the flow in order to reduce Δt to a moderate value.

At 220 ata and a relatively small heat flux (q = 0.25 × 10^6 kcal per sq m hr), wall overheating is observed even with subcooled liquid (Fig. 3); the maximum overheat, i.e., the minimum value of the heat-transfer coefficient, is near the boiling point. This coefficient rises rapidly with an increase of the dryness factor (at G_0 = const) and it begins to fall again only in the superheat zone. It is interesting to note that at the beginning of evaporation the heat transfer coefficient is considerably less (4–5 times) than with slightly superheated steam (at the same G_0). These data show that near the critical point the heat exchange conditions undergo considerable changes, and that great surface overheating can take place.

It might be concluded that the above data confirm the undesirability of once-through boilers designed for near-critical pressure (7). However, the same experiments have shown that the increase of flow weight velocity (G_0) has great influence on the intensity of heat exchange. For instance, at a heat flux of 270,000 kcal per sq m hr and a pressure of 220 ata (3130 psia) the two-fold increase of G_0 raises the heat-exchange coefficient by 5–6 times. Of course this is connected not only with the reorganization of the flow at film evaporation, but also with a considerable change in the physical properties of the steam flowing near the heating surface.

Therefore, the use of considerable values of weight velocity at the temperature zone near the critical one (375 C) permits avoiding a considerable increase in the temperature of tube walls in boilers operating at a near-critical pressure. It is important to note that with a heat flux in conventional pulverized coal-fired boilers moderate velocities of the flow (of about 1500 kg per sq m sec) are sufficient. These velocities do not result in any noticeable rise in the hydraulic resistance of the boiler.

From the point of view of safeguarding a reliable cooling of steam-generating tubes, one cannot consider as undesirable the operation of large pulverized coal-fired once-through steam boilers at near-critical pressure. On the basis of experimental data on the heat exchange between the heating surface and the working substance, one can select the weight velocities of the flow securing a reliable cooling of tubes at a moderate hydraulic resistance of a given steam generator.

One cannot expect that the tube cooling conditions at pressures much higher than the critical one ($P > 300$ ata) are more favorable than those at subcritical pressures.

It has been frequently assumed that a pressure increase above critical in the zone of flow temperatures less than 375 C (707 F) is desirable to avoid the danger of separation of the steam-water mixture in horizontal tubes, as well as unequal distribution of steam and water after mixing headers. However, a weight velocity value sufficient for reliable tube cooling at supercritical pressure is none the less necessary for avoiding steam-water mixture separation. Yet, the use of mixing headers in the zone of temperatures below the critical one is not necessary as the specific heat of the steam in this case is very high and, therefore, temperature difference in parallel connected coils is negligible. From the design viewpoint the mixing headers are also unnecessary, at least for the *Ramzin* and *Sulzer* once-through boilers.

On the whole, it may be stated that from the viewpoint of reliability of steam-generating tube cooling there exist no substantial reasons to prefer subcritical or slightly supercritical pressures, or pressures above 320 ata (4560 psia).

Reliable operation of once-through boilers can be maintained within the whole range of pressures above 100 ata (1422 psia). The considerations connected with the operation of once-through boilers at the transitional conditions do not represent any substantial restrictions in the choice of pressures. There can be no doubt that with the rise of pressure the operation stability of once-through boilers increases, and control conditions become less complicated. These changes, however, are significant only at pressures from about 30–40 to 100–120 ata; further pressure increase results in small changes. At pressures of 100–120 ata (1422–2000 psia) once-through boilers operate quite steadily. Further increase in pressure changes the dynamic characteristics of once-through boilers very little (8), and the transition of the critical pressure causes no qualitative changes.

The generation of high purity steam with a total content of solids from 0.05 to 0.15 ppm, including SiO_2 not exceeding 0.02–0.03 ppm, is very important for reliable operation of a steam-power installation. At low pressures the solubility of salts in steam is very small, and the main part of impurities in the feedwater is, in case of complete evaporation of boiler water, deposited on the inner surface of the tubes. Only a very small part of solids is carried with the steam in minute solid particles. At the end of the evaporation zone the deposits of water-soluble salts are washed away and are partially carried by the steam, resulting in a short-time increase of the salt content of the steam.

Under normal conditions the purity of steam of once-through boilers is practically completely defined by the value of solubility in steam of the solids contained in

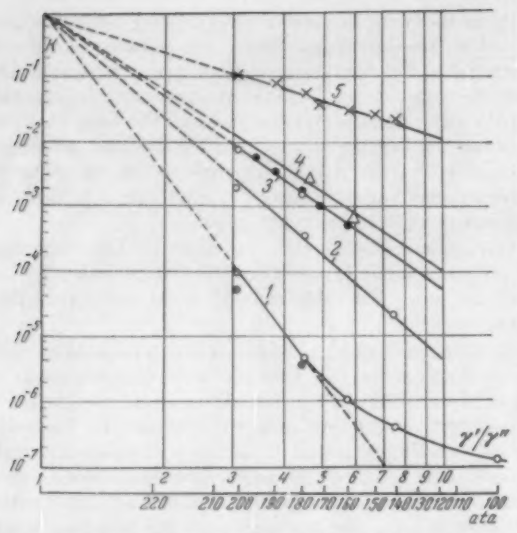

Fig. 4—Dependence of distribution factor upon relation of phase densities

1. ○—$NaSO_4$ ○—$CaSO_4$
2. ○—$CaCl_2$
3. ●—NaCl
4. Δ—NaOH
5. ×—SiO_2

the feedwater. Therefore, the investigation of solubility in steam of the main solids, which feedwater usually contains, is very important.

Although the solubility of salts in steam was observed many years ago, more or less reliable and complete data on the solubility of some substances (mainly NaCl and SiO_2) were determined for the first time by *Straub* (9). This problem has been subjected to detailed investigation at the *MEI—Moscow Power Institute* (*Styrikovich, Katkovskaja and Samoilov*) (10) and at the *ENIN* (*Styrikovich, Haibullin and Zhvirashvili*) (11). These studies have ascertained that the distribution factor of a given substance between steam and water is a simple function of densities of both phases:

$$K = \frac{C_{st}}{C_w} = \left(\frac{\gamma_{st}}{\gamma_w}\right)^{\bar{n}} \qquad (1)$$

where: $\bar{n}$ = constant for the given substance. The value of the exponent $\bar{n}$ in the formula (1) greatly depends on the nature of the substance. Weak acids, silicic acid for instance, have a high value of k; the distribution factor for chlorides and hydroxides is considerably lower, and its value is very small for sulfates (Fig. 4). At a given pressure $\bar{K}$ is constant within a wide range of concentration; it drops only for salts of very high solubility, for instance for NaCl, within the range of concentrations approaching saturation, when the temperature of the aqueous solution is much higher than the boiling point of pure water.

The salt content in steam is highest in equilibrium with an aqueous saturated solution. With further rise of steam temperature the concentration of salts in superheated steam, which is in equilibrium with a solid salt, decreases. It attains its minimum value at a temperature exceeding the boiling point of the saturated solution by 50–70 deg C (90–126 deg F) (Fig. 5). At this point the solubility is considerably lower than in the equilibrium with a saturated solution (about four times). With a subsequent increase of temperature the solubility increases again.

Multicomponent solutions have been little investigated; only a number of experiments with binary solutions (NaCl + NaOH; NaCl + LiCl; NaCl + Na_2SO_4) have been made. They have shown that solubility in steam of some salts in the presence of the solution of another salt, even with the same ion, is practically the same as in solo-solution. This allows to calculate the solubility in steam of each of the salts independently from the presence of other salts at the first approximation.

The salt contents in steam calculated on the basis of the data of the salt solubility in steam closely correspond to the data of research work of the Moscow Division of the Central Boiler-Turbine Institute on salt deposits in an experimental coil of a once-through boiler. According to these investigations the salt contents in the steam, at a dosage of salt to the feedwater in a quantity exceeding its solubility (minimum) in steam, are the same as in the case when pure steam passes through a tube covered with deposits of the given salt. This proves that complete equilibrium between salt and steam is practically reached in the tubes of a once-through boiler.

Solubility in steam of hydroxides of alkali metals (NaOH, KOH) and of all chlorides we are practically interested in, as well as of weak acids (silicic acid), exceeds by many times the ordinary contents of these compounds in the feedwater of once-through boilers at a pressure above 100 ata; therefore, these compounds are completely dissolved in the steam. On the other hand, the solubility of sodium sulfate in steam is equal only to 0.02–0.03 ppm, even at a pressure of 180 ata (2560 psia), and it drops abruptly at lower pressures. Therefore the steam of once-through boilers contains, as a rule, very little of Na_2SO_4. In case of noticeable contents of sodium sulfate in feedwater, its surplus can be deposited on tube surfaces even at pressures of 100–140 ata (1422–2091 psia). At higher pressures of about 180–220 ata (2560–3128 psia) the solubility even of sodium sulfate in the steam is higher than its usual contents in feedwater; therefore Na_2SO_4 completely leaves the boiler with the steam.

The solubility of $CaSO_4$ in steam is very low; it comprises about 10^{-4} ppm, even at a pressure of 200 ata (2844 psia) (12). Therefore, calcium sulfate deposits

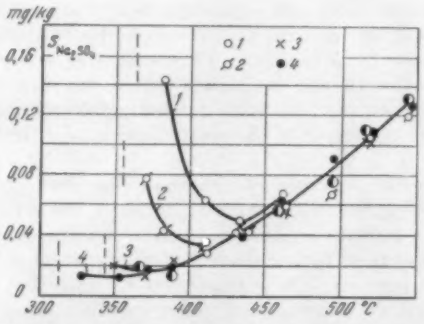

Fig. 5—Dependence of solubility of sodium sulfate in water vapor upon pressure and temperature

1. 200 ata (2844 psia)
2. 180 ata (2560 psia)
3. 140 ata (2091 psia)
4. 100 ata (1422 psia)

on the walls of the transition zone in the presence of any noticeable quantity of Ca^{2+} and SO_4^{2-} in feedwater. It seems that the solubility of a number of magnesium compounds, as well as $Ca(OH)_2$ in steam is very low; the presence of $Ca(OH)_2$ in deposits in a once-through boiler with a pressure at superheater outlet $P = 140$ ata (the pressure in the transitional zone being 150–160 ata) is explained by this fact.

It can be seen from the above that already at a pressure of 100–140 ata (1422–2091 psia) the solubility in steam of most of sodium compounds contained in feedwater exceeds their permissible content in steam. Therefore, at high pressures it is necessary that the content of these substances in the feedwater should not be higher than their permissible concentration in steam in order to obtain the required purity. Consequently, there should practically be no deposits of sodium compounds.

Under these conditions steam separators can be used for sodium salts extraction from the cycle of a power station. Steam separators can be successfully used in once-through boilers of *Sulzer* type as well as in a number of new modifications of once-through *Ramzin* boilers (13). Comparatively satisfactory operation of the *Sulzer* once-through boilers has been obtained even with the steam turbine condensers operating with sea water cooling in one of the power stations in the U.S.S.R.

Steam separators, however, become noneffective at a pressure approaching the critical one; at a steam pressure at the superheater outlet of $P \geqslant 215$ ata (3060 psia) [the pressure in transition zone being 230 ata (3270 psia)] they are generally inapplicable. In these cases other methods must be chosen to ensure the required purity of steam (14). First of all it is necessary to reduce the quantity of salts entering the steam-power cycle by means of sealing the condensers as perfectly as possible and by using makeup water of a very high purity. Some of the power stations in the U.S.S.R. have reached a certain success in this respect. They have succeeded in reducing the condenser leakage to less than 0.005–0.01 per cent of steam consumption by means of a thorough control, and especially by using condensers equipped with double plates to feed the condensate under an overpressure between the plates. Steam washing with feedwater or condensate is successfully used in evaporators. This makes it possible to obtain distillate of a very high purity even with high content of salts in the boiling water of the evaporator.

These arrangements, however, are insufficient to provide for purity of steam in supercritical installations. Cooling water usually contains 400 ppm of salts; in this case a leakage of 0.005 per cent results in entering of about 10 kg of salts per 1000 hr into the cycle of a big turbine, even with practically zero salt contents in the distillate, or in demineralized makeup water. This is at least 10 times more than the value of the deposits which can be allowed for a turbine for such a period. Therefore, it is quite natural that the extraction of salts should be carried out from such a part of the cycle where two phases exist (water and steam), and where the separation and extraction of water with high contents of salts is possible. Such parts of a cycle are the last stages of a condensing turbine. At present in the U.S.S.R. research work is being carried out to investigate the possibility of "continuous blow down" for turbines. A special water separation device generally provided for turbines should be used for this purpose leading the drainage to a separate condenser. Usually the drainage flows to the main condenser where the separated water is mixed with the whole mass of the condensate.

This method cannot be used in case of very high temperature of reheat when the steam wetness at the end of expansion is very low. In these cases it is possible to separate the moisture formed at the first stages of condensation either in main condensers or in regenerative heaters. This separated water enriched with salts may be extracted from the cycle or demineralized.

The foregoing concerns power stations where feedwater contains mainly sodium compounds. This occurs in all power stations where both once-through and drum-type boilers operate. In power stations where only once-through boilers are operating this takes place where makeup water is being prepared in evaporators, and the main part of solids in the turbine condenser cooling water consists of sodium compounds (sea water, river water of some regions of the U.S.S.R.).

Most of the new power stations equipped with once-through boilers only will have demineralized makeup water, and the condenser cooling water will contain mainly calcium compounds. In this case a noticeable percentage of the substances contained in the feedwater will be deposited even in boilers operating at a supercritical pressure. Consequently, the problem of extracting salts from the cycle will be solved with less difficulty.

BIBLIOGRAPHY

(1) M. A. Styrikovich and Z. L. Miropolsky, "Influence of Dimensions of Horizontal Steam-Generating Tubes on Their Temperature Conditions," papers of the Academy of Sciences of the U.S.S.R., 1952.

(2) M. A. Styrikovich and Z. L. Miropolsky, "On Influence of Angle Inclination on Temperature Conditions of a Steam-Generating Tube Wall at High Pressures," papers of the Academy of Sciences of the U.S.S.R., 1951.

(3) E. G. Deissler, "Heat Transfer and Fluid Friction for Fully Developed Turbulent Flow of Air and Supercritical Water with Variable Fluid Properties," *Trans.* ASME, **76,** No. 1, p. 73.

(4) L. E. Kalihman, "Gas-Dynamical Theory of Heat Exchange," *J. Appl. Math. and Mechanics,* No. 10, issue 4 (1946).

(5) M. A. Styrikovich, "Intraboiler Processes," pages 96–107, Energoizdat, Moscow, 1954.

(6) M. A. Styrikovich and M. E. Shizman, "New Data on Temperature Conditions of a Steam-Generating Tube at Superhigh Pressures," papers of the Academy of Sciences of the U.S.S.R. 1954.

(7) J. Bartels, "Thermodynamics Favors Supercritical Steam Pressures," *Elec. Light & Power,* **32,** No. 13, 102 (1954).

(8) and (9). E. P. Serov, "Operation of Once-Through Steam Generators at Variable Conditions," works of Moscow Power Institute (MEI), issue XI, 204, 1954.

(10) M. A. Styrikovich, "Intraboiler Processes," p. 261–265, Energoizdat, Moscow, 1954.

(11) M. A. Styrikovich, I. H. Haibullin and D. G. Zhvirashvili, "Investigation on Solubility of Salts in High-Pressure Steam," papers of Academy of Sciences of the U.S.S.R., 1955.

(12) M. A. Styrikovich, "Investigation of Carry-Over of Salts with Steam and Hydrodynamics of Two-Phase Liquid by Method of Radio-Active Isotopes," the works of the Session of the Academy of Sciences of the U.S.S.R. on Peaceful Use of Atomic Energy, Meetings of Technical Science Division. Publishing House of the Academy of Sciences of the U.S.S.R., p. 210, 1955.

(13) N. I. Koskelev, "Operation of Once-Through Boilers at Washing-Separation Condition," *Teploenergetica,* No. 2 (1954).

(14) M. A. Styrikovich, "Methods of Salt Removal from Cycle of Steam-Power Installation at Supercritical Pressure," *Teploenergetica,* No. 1, 31 (1955).

(15) U. M. Kostrikin and A. I. Filimonov, "Removal of Salts and Silicic Acid from Steam-Power Cycle by Means of Turbine Blowing Down," *Teploenergetica,* No. 1, 34 (1955).

(16) M. A. Styrikovich, M. E. Shizman and Z. L. Miropolsky, "Some Data on Temperature Conditions of a Vertical Steam-Generating Tube at Subcritical Pressures," *Teploenergetica,* No. 12, 32 (1955).

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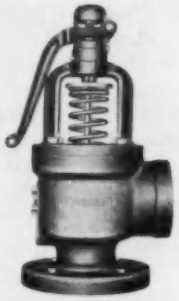

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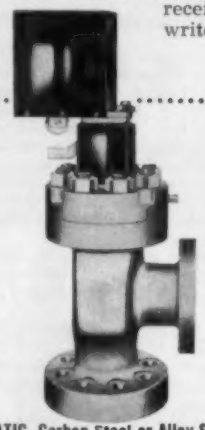

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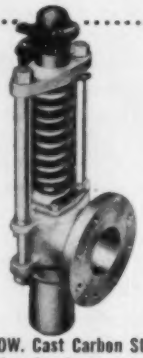

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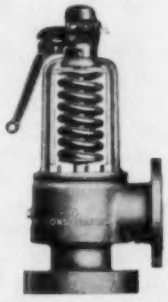

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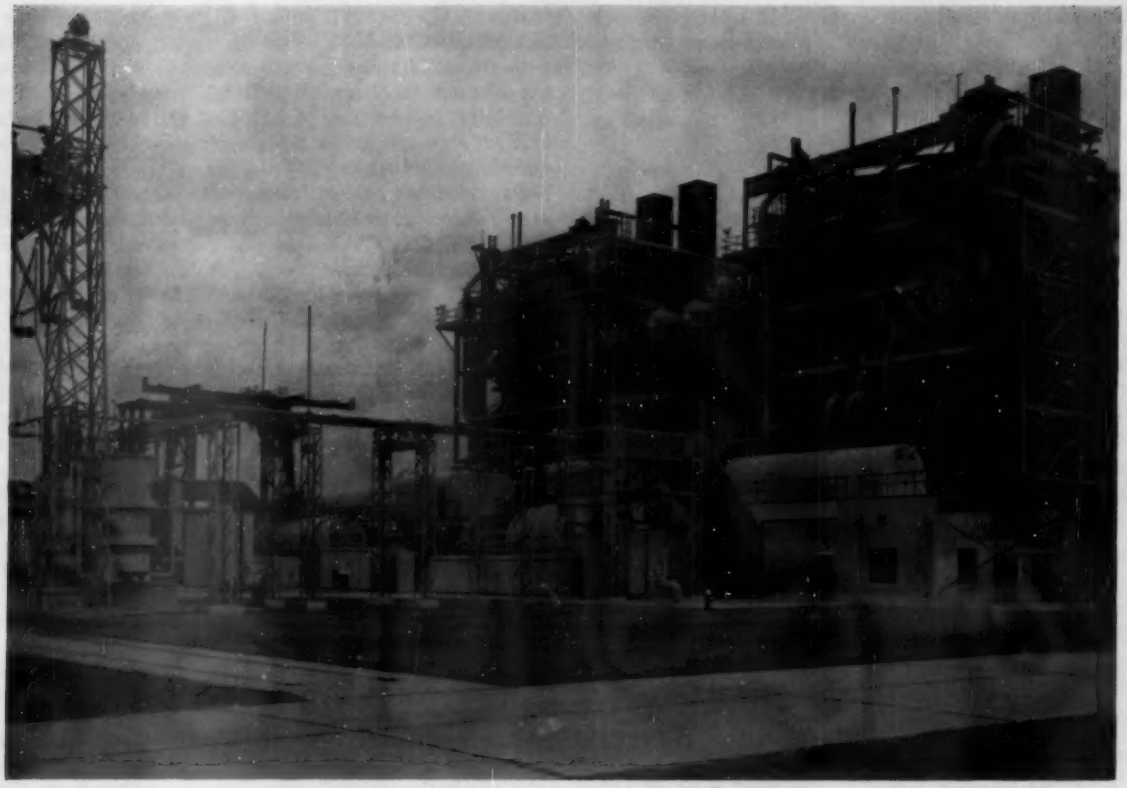

Outdoor Versus Indoor Steam-Electric Stations in the Houston Area*

By L. K. DEL'HOMME

The relative merits of outdoor and indoor steam-electric stations covering the design, construction, operation and maintenance of generating stations vary from area to area. However, the Houston Lighting & Power Company has resolved this question definitely in favor of full outdoor plants on the basis of experience in the Texas Gulf Coast Area.

CLIMATIC conditions are important in the construction, operation and maintenance of outdoor generating stations. In the Houston area, the climate is mild with temperatures reaching the low 90's daily during the summer and with infrequent short spells of below-freezing weather in the winter. According to the 53-year record of the Houston weather station, the three coldest months of the year are December, January and February, during which the mean minimum temperatures range from 44.9 F to 47.1 F. The annual mean minimum temperature is 60.3 F. Snow and sleet are rare. Over the period of record, average annual rainfall is 45.7 in., spread fairly uniformly over the 12 months. However, heavy deluges are not uncommon, particularly in the winter and spring months.

The area is subject to occasional tropical storms and hurricanes, usually in the July-September period. According to records of the U. S. Weather Bureau, 32 hurricanes have come inland from the Gulf of Mexico along the Texas Gulf Coast since 1895. This coast line is over 600 miles in length and only a small number of these storms have actually passed through the Houston Lighting & Power Company service area.

Power Requirements and Supply

System net max-hr load in 1955 was 1077 mw, or about 1.6 times the 1951 peak, representing an average annual rage of growth of 12.1 per cent which approximates the average rate of growth since 1933. The 1959 system load is expected to be 1577 mw which is an increase of one-half million kw in four years.

To meet the 1955 power requirements the total net generating capability on the system was 1256 mw. This capability, all of which is in gas-fired steam-electric units, is concentrated in five major stations in the Houston

* Presented before the AIEE Summer and Pacific General Meeting, San Francisco, Calif., June 25-29, 1956.

area, and one small standby plant in Galveston. The major stations, all of which are interconnected by a tightly coupled transmission network encircling and traversing the City of Houston, are:

Gable Street: 7 units, 80 mw
Deepwater: 7 units, 318 mw
Hiram O. Clarke: 4 units, 250 mw
Greens Bayou: 4 units, 364 mw
Webster: 2 units, 220 mw

To meet the 1959 power requirements it is expected to have available an additional 660-mw capability consisting of one 165-mw unit recently placed in service at Sam Bertron Station, and a second 165-mw unit at Sam Bertron and two 165-mw units at the new Smithers Lake Station now under construction, or a total capability of 1895 mw.

Evolution of Outdoor Station

The mild climate of the Houston area coupled with capital cost advantage directed attention to the outdoor station design. The first step in this direction was taken in 1939 when a 25-mw extension was made to the Gable Street Station. This included a semi-outdoor boiler with enclosure or hood extending down from the roof to below the drum level. The turbine room was of conventional design, an extension of the older building.

This rather modest start was followed, in sequence, in 1943 and 1947 by the first two units at the Hiram O. Clarke Station. Satisfactory experience with the Gable Street extension coupled with the very short supply of critical materials during the war years suggested the prudence of taking one more step toward outdoor design. Accordingly, in 1943 a 37.5-mw unit was installed at the then new Hiram O. Clarke Station. Here the turbine as well as the boiler was a semi-outdoor installation. The turbine-generator was of conventional indoor design provided with a metal enclosure with a sectional roof, removable for access and major maintenance by the station crane. Installation of a duplicate unit at this station was completed in 1947.

Advances made in the development of outdoor station design and of equipment suitable for outdoor installation, permitted installation in 1949 of the Company's first full outdoor station. This was the Greens Bayou "A" Station, which consists of two 60/66-mw preferred standard units with a combined capability of 145 mw. All auxiliaries including the 2300- and 480-volt switchgear are located outdoors except for the boiler feed pumps which are more or less protected by the control room located above them. The motors are of the conventional splash-proof design with the addition of extensions on the ventilation openings to protect against driving rain. The turbines are protected against the weather by a streamlined metal cover, while the generator casings are in themselves weather-proof. Walk-in housings are provided for the main exciter and the turbine front end. Space under the generator houses the spare exciter, generator leads, surge protection, neutral grounding transformer and instrument transformers, as well as field rheostats and circuit breakers, station battery and battery charger.

The Greens Bayou "A" Station has served as a model for subsequent outdoor power supply additions. The Hiram O. Clarke "B" Station with two 60/75-mw units was completed in 1951. The Greens Bayou "B" Station with two 80/100-mw units was completed in 1953, and the Webster Station with two 80/100-mw units, in 1954. The latest full outdoor plant added to the system is the first 125/156-mw unit at Sam Bertron Station which was completed this year.

In addition to these full outdoor capacity additions, semi-outdoor extensions were made to the existing conventional indoor Gable Street and Deepwater Stations in 1950 and 1955, respectively. Had these units been located at one of the full outdoor stations, they too would have been of this design.

The past and expected future trend toward outdoor station design on the Houston System is shown in Table I. In the four-year period from 1952 to 1956, name plate capacity of full outdoor type stations increased from 282 mw, or 45.9 per cent of the total, to 838 mw, or 63.1 per cent, and is expected to amount to 1306 mw, or 72.8 per cent of the total in 1959. Experience thus far with outdoor type generating station construction and operation has been entirely satisfactory; nothing has occurred which would suggest that our present policy should be reversed or even modified.

Investment Costs

Investment or capital cost is a major factor in choosing between an outdoor or a conventional indoor plant.

A survey (1)[1] made by Electrical World in 1955 indicated that the investment cost for representative outdoor stations in the 60- to 74-mw class was a little more than half the cost of the average indoor stations. However, it was pointed out that the savings becomes less as station size increases, amounting to about $17 per kw for a station of 150 mw or more. Since no conventional indoor plant has been constructed on the Houston System since 1932, comparable actual cost data for indoor and outdoor plants are not available. However, it is estimated that at least $10 per name plate kw is saved by the full outdoor type of construction with a proportionately smaller saving for the semi-outdoor type.

The Electrical World survey (1) reported on 54 modern steam-electric stations with ownerships designated by code number only. The station ratings are based on Manufacturer's Maximum Rated Capability (MMRC) and rating groups designated by Roman numerals. Group VIII, which identifies the 300- to 499-mw range, includes nine stations, one of which, No. 247 is a full outdoor, gas-fired plant located in the Gulf Coast Area. The remaining eight stations, while not so identified, appear to be the indoor or semi-outdoor type, equipped to burn coal. Comparison of these stations, which are shown in Table II, indicates that the cost of $74.19 per kw for station No. 247 is the lowest of the Group VIII stations. Costs of the remaining eight Group VIII sta-

TABLE I—GROWTH OF THE OUTDOOR STATION ON THE HOUSTON SYSTEM

	Installed Capacity-Name Plate					
	Mw			Per cent		
Type of Station	1952	1956	1959	1952	1956	1959
Indoor	200	200	200	32.5	15.1	11.1
Semi-outdoor	133	289	289	21.6	21.8	16.1
Full outdoor	282	838	1306	45.9	63.1	72.8
Total	615	1327	1795	100.0	100.0	100.0

[1] Numbers in parentheses refer to References at the end of the article.

tions range from $80.70 to $189.70 for an average of $134.95. As a matter of general interest, two additional full outdoor gas-fired stations, both located in the Gulf Coast Area, have been included in Table II although neither falls in the 300- to 499-mw group. These two plants are identified as Stations M and N.

Of particular interest is Account 311—Structures and Improvements—which includes plant buildings. For station No. 247, investment in this account is $8.60 compared to costs for the remaining eight Group VIII stations ranging from $21.03 to $51.80. Investment in Account 311 for stations M and N is $13.98 and $16.43, respectively. This comparison, while undoubtedly including more items for coal-burning plants than for gas-fired stations, points up the high cost of enclosures for the boilers and turbines.

While Table II does tend to support the thinking that outdoor plants are cheaper than indoor plants, it should not be taken as an exact measure of the difference in cost. Such comparisons must be tempered by such other factors as steam pressure and temperature, heat cycle, type of fuel, cooling water system, foundation conditions, type of buildings required and choice of equipment. In so far as available data permit, these factors are also shown in Table II.

All other factors being equal the major saving in an outdoor plant is largely due to the elimination of costly boiler and turbine buildings. The above referenced survey reports, for the Group VIII stations, combined boiler and turbine room space factors ranging from 16.03 to 24.75 cu. ft. per kw. On the basis of the minimum space factors reported, the construction of an additional 5.3 million cu. ft of buildings would have been required to house the boiler and turbine-generator for outdoor station No. 247. Because of the variety in types of building construction and other factors it is difficult to assign a dollar value to this saving, but it is obvious that it is of substantial magnitude. On the basis of the estimated saving of $10 per kw, previously mentioned, the total saving realized in the construction of the 838,000 kw of outdoor type generating capacity on the Houston System in 1956 is estimated at $8,380,000. Moreover, between 1956 and 1959 an additional saving of $4,680,000 will be realized on the installation of 468,000 kw of generating capacity now under construction. Savings of this proportion, especially during these years of rising prices, dictate close study of the outdoor plant design before rejecting it.

Design

Adoption of the full outdoor plant design is in accordance with the broad system planning axiom of satisfying load requirements at the lowest possible long term cost commensurate with the standard of service required. On the Houston System, the full outdoor design does represent the minimum in capital cost and does result in satisfactory operating and maintenance conditions and costs.

As suggested above, the Greens Bayou 1949 installation, with all major equipment placed in the open, has served as a prototype of subsequent stations. While improvements and refinements have been made, the basic outdoor design has remained unchanged which in itself tends to reduce engineering and construction costs. Advantage is taken of the shelter provided by the operating center and the turbine-generator deck to provide protection for certain equipment and piping. Elimination of boiler and turbine enclosures and basements simplifies construction and minimizes foundation requirements. The only building forming part of the plant proper is the control room. A service building housing the machine shop, office, laboratories and locker facilities along with a separate store house and the substation control house comprise the remaining buildings.

Actually, major disadvantages of outdoor plants arise from exposure of personnel and equipment to the weather. But as was shown earlier, the Houston area enjoys favorable weather conditions for this type of plant although moisture does present special problems.

General practice is to construct plants in multiples of two units, with a common control room located between the boilers and at the same elevation as the turbine-generator deck with the major auxiliaries located at ground level. On p. 55 is a photograph of a typical full outdoor station showing the general layout from the turbine-generator side. As may be seen, all of the major equipment is located in the open.

A description of the major electrical equipment for the

TABLE II—STATION COSTS AND GENERAL DATA FOR ELEVEN MODERN STEAM-ELECTRIC STATIONS

	Nine Group VIII* Stations Included in Electrical World Survey									Additional Stations†	
	241	242	243	244	245	246	247†	248	249	M	N**
Investment Data (Dollars per Kw)											
(311) Structures, improvements‡	32.57	29.47	30.49	51.80	42.27	47.70	8.60	39.01	21.03	13.98	16.43
(312) Boiler plant	46.59	47.04	49.72	79.10	60.42	61.20	25.68	50.57	32.41	30.62	34.52
(314) Turbine-generator	30.21	37.70	34.17	35.40	40.15	37.60	33.63	32.54	22.81	34.94	35.62
(315) Accessory elec. equipment	5.26	4.97	9.27	21.70	12.76	9.94	6.11	7.22	3.24	5.69	6.34
(316) Misc. plant equipment	1.13	1.57	0.94	1.70	3.41	2.31	0.17	1.01	1.21	0.29	0.37
Total, excluding land and substation	115.76	120.75	124.66	189.70	159.01	158.75	74.19	130.35	80.70	85.52	93.28
General Data											
First operation, year	1953	1952	1948	1953	1952	1952	1949	1952	1941	1954	1956
Newest unit, year	1954	1854	1953	1954	1954	1954	1953	1953	1951	1954	1956
Total generator rating, MMRC*	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VII	VII
No. of turbo-generators	3	4	6	2	3	3	4	3	4	2	1
Range of unit ratings*	VI	VI	IV	VII	VI	VI	IV–VI	VI	IV–V	VI	VII
No. of boilers	3	4	6	2	3	3	4	3	4	2	1
Range of boiler ratings, M lb/hr	875	675	430 & 500	1370	860 & 875	706 & 820	675 & 950	690 & 850	640 & 725	950	1200
Steam pressure, psi	1850	1492	1350 & 1500	1800	1250 & 1450	1500 & 1850	920 & 1525	1650	890	1525	1925
Steam temp, supht., F	1050	1000	950 & 1000	1000	950 & 1000	1005	905 & 1005	1000	910 & 950	1005	1005
Reheat, F	1000	1000	1000	1000	1000	1005	...	1000	...	...	1005
Cooling water range, F	33–72	37–76	43–103	33–77	33–83	32–85	72–94	33–85	35–75	56–95	56–88
Coal-burning facilities	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No

* Rating groups (manufacturer's maximum rated capability), MW: IV, 60–74; V, 75–99; VI, 100–149; VII, 150–299; VIII, 300–499. † Full outdoor, gas-fired stations in Gulf Coast Area. ‡ Electric plant account numbers prescribed by Federal Power Commission. ** Investment data partially estimated.
Source of information: Cost and Performance Data of 54 Modern Steam Stations, *Electrical World*, October 17, 1955, pp. 136–139. Operating Company Records.

first unit at Sam Bertron Station will serve as a guide to the type of outdoor equipment utilized on the Houston System. Except for the fact that this is a completely outdoor unit, it is almost a duplicate of the one installed in the Deepwater S.E. Station 1955 semi-outdoor extension, which is discussed in some detail in an article by Mr. A. P. Priddy which appeared in the January 1956 issue of *Southern Power and Industry* (2). Reference is made to this article for mechanical features.

Turbine-Generator. The turbine-generator is of General Electric Company manufacture, rated 125,000/156,250 kw, tandem compound double flow (bottom exhaust) 3600-rpm, 1800-psig, 1000 F-reheat cycle. It is designed for operation at $3^1/_2$-in. Hg, 3 per cent makeup using six extraction points for feedwater heating.

The generator is hydrogen cooled, rated 150,000 kw 176,470 kva at 0.5-psig hydrogen pressure, 0.85 pf, 20,000 volts, 3-phase, 60 cycles. It is designed for operation at 30 lb hydrogen pressure with a rated capability of 221,000 kva and 187,850 kw at 0.85 pf. The unit is provided with a gear connected shunt wound main exciter, rated 550 kw, 375 volts, and amplidyne voltage regulator. The turbine exhausts to an 85,000-sq ft condenser of the single shell, single pass, divided water-box type located under the turbine exhaust and is provided with the usual auxiliaries.

The outdoor features of the Sam Bertron turbine-generator include weather-proofing of the hydrogen seal oil unit and control panel, inlet stop valves, reheat stop valves, intercept valves, lubrication oil system and associated equipment, turbine start-up panel and supervisory instrument panel. The generator itself presents no special water-proofing problems as the casing is of necessity hydrogen-tight. In the Houston area thermal insulation of the generator is not required. Protection of the front end of the turbine is afforded by a weather-proof cap; on some other units the front standard is protected by a walk-in housing. A standard walk-in housing is also provided for the exciter. The exciter ventilating system is of the non-recirculating type with forced air taken in through filters mounted below the floor and exhausted to the outside below the floor line. Air paths are arranged to carry away carbon dust and oil vapor. Cost of weather-proofing will vary with the size of the unit and to the extent applied. Based on book prices weather-proofing increased the cost of the Sam Bertron unit by about 2 per cent, or $0.58 per name plate kw.

The manufacturer recommends that the lubricating-oil temperature be above 50 F before rolling the turbine-generator. To accomplish this, provision is made for supplying hot water to lubricating-oil coolers when the unit is down. It is also recommended that an oil pump be kept running during shutdown. So far it has not been considered necessary to provide special means of controlling the temperature of the armature coils during a shutdown. This protection can be readily added by making provision for passing hot water through the gas coolers.

Motors for driving turbine-generator auxiliaries, such as the turning gear and oil pumps, are of the totally enclosed type. On an indoor or semi-outdoor plant these motors would be of the indoor type.

Motors. In the application of outdoor station design, protection must be provided for motors, as well as for turbine-generators, against moisture, dust and other solid particles and temperature extremes. In the smaller sizes, 60 hp and less, totally enclosed motors are generally used. Above this rating the motors are usually of the weather-protected type.

For the Sam Bertron 165,000-kw unit, 13 large auxiliary motors as shown in Table III were purchased. These are all of the weather-protected type, ranging from 125 to 2500 hp and from 514 to 3600 rpm. All are equipped with filters and electric space heaters.

Those driving the circulators, condensate pumps, and the cooling service water pumps are of the vertical type. The remaining motors are the horizontal type.

Cost of weather-protected enclosures for motors varies with the speed and rating. For example, using drip-proof motors as a base, enclosures for the 2500-hp, 3600-rpm motors added about 10 per cent to the base prices, while for the 1000-hp, 900-rpm motors the increase was about 25 per cent. To this must be added the cost of filters and space heaters.

The price increase for weather-protection for all 13 motors was approximately 17 per cent or $0.23 per turbine-generator name plate kw. Had totally enclosed motors been chosen the price increase over drip-proof motors would have been 78 per cent or $1.04 per kw.

The foregoing indicates that the use of outdoor type motors involves a sizeable premium in purchase price. This disadvantage is offset by the fact that expensive

Fig. 2—The Webster steam-electric generating station under construction

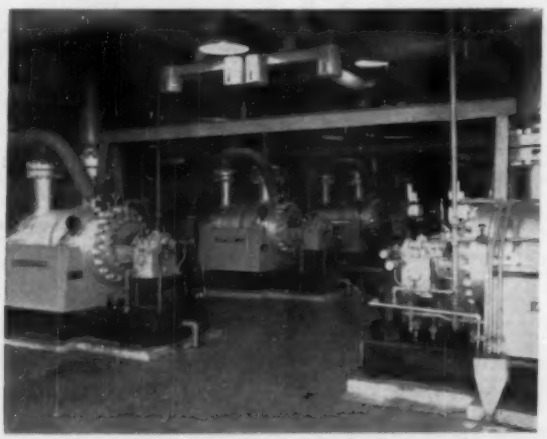

Fig. 3—Shelter provided by the outdoor-type structure for equipment and piping

building enclosures are not required, and more freedom is allowed the plant designer in locating this equipment, which normally results in shorter pipe runs and a more compact installation. Moreover, the outdoor structure itself can be utilized to provide partial protection from the weather, as is evident from Fig. 3.

Recent developments in motor insulations look very promising. Manufacturers of new insulation claim that its superior electrical, thermal, mechanical and chemical properties remain almost unchanged with use even under adverse conditions. While actual operating experience is almost nil, laboratory tests, including accelerated aging, seem to bear out the claims. Prices are expected to be in line with motors having conventional insulation.

With this type of insulation, outdoor motor application would no longer be a special problem calling for motor enclosures to offset the limitations of conventional insulations. For example, all outdoor motors could be of the drip-proof type and could reasonably be expected to give long and trouble-free service in so far as insulation is concerned.

Such advances as this will certainly go far toward removing one major disadvantage of outdoor power plants.

Auxiliary Equipment. The absence of building walls and basements and the use of a minimum number of floor levels contribute to the inherent compact design of the outdoor stations. This feature, which permits closer proximity of auxiliary equipment, results in shorter cable and bus runs. Moreover, in indoor plants a large number of exposed electrical conduits or cable trays are necessary. While cable trays may be used in outdoor plants, many of the electrically driven auxiliaries are located at grade level, thus permitting underground installation of cables. Besides being economical and trouble free, this eliminates overhead and exposed electrical conduit and cable installations from much of the plant area.

Both the medium and low voltage switchgear are of the outdoor weather-proof design, and, as in the case of most other electrical equipment, are more expensive than indoor gear. However, the outdoor gear with throat-connected transformers results in simplification in design which, coupled with the savings effected by outdoor construction, outweighs the difference in purchase price.

For each generating unit the 2300-volt switchgear is divided into two busses, each of which is supplied from a throat-connected 6000-kva, 19450/2300-volt transformer and provided with an alternate feed from a 7500-kva 66/2.3-kv standby auxiliary transformer. In this installation there is a total of twenty 2300-volt cubicles. The cost for weather-proofing, approximately $1000 per cubicle, amounts to a total of $20,000 in this case. The second installation, now underway at the Sam Bertron Station, will require a similar outlay.

In contrast to the 2300-volt gear, the cost of weather-proofing 480-volt switchgear is based on the number of breakers purchased and their interrupting rating, irrespective of the number of cubicles required. For two units at Sam Bertron Station, the total cost of weather-proofing the 480-volt switchgear will approximate $6500.

Thus, for two 165,000-kw units, the total cost of weather-proofing of all auxiliary switchgear will be about $46,500, or about $0.15 per generator name plate kw.

Other Electrical Features. Generator leads for outdoor stations on the Houston System are of the segregated-phase design inside of the generator pedestal and are of overhead, open type construction with a Micarta type protective sleeve from the pedestal to the step-up transformer bank. Fig. 6 illustrates the overhead portion of the leads. It shows the protective enclosure provided to guard against damage by the station crane or other operations on the turbine-generator deck. For the first time at an outdoor station on the Houston System, the generator leads at Sam Bertron are fabricated of aluminum rather than copper. Here, the leads within the pedestal are formed of two 10-in. aluminum channels per phase with all joints bolted. The phases are segregated by transite barriers mounted on aluminum frames. From the pedestal to the transformer bank the leads are made of 10-in. O.D. aluminum tubing with all joints welded. Aluminum tubing rather than channel was used for the outdoor portion of the leads because of the difficulty and expense of obtaining a satisfactory protective covering for the channel. Neither circuit breakers nor disconnecting switches are used between the generator and the transformers, the generator circuit breaker being located in the high voltage switchyard.

Main power transformer bank for the 165,000-kw generating unit consists of three 75,000-kva, 19/66-kv, single phase, FOA, transformers, which are identical with

Fig. 4—Exterior view of a typical operating center

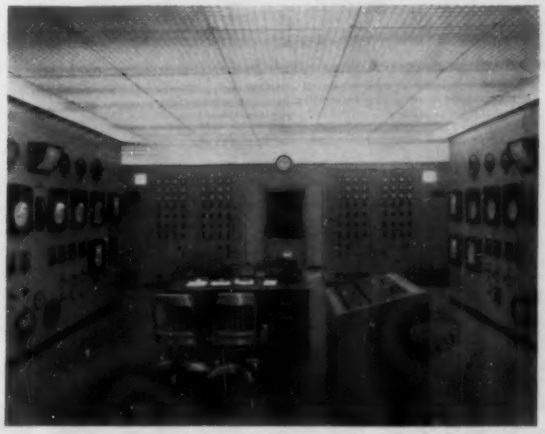

Fig. 5—Interior view of a typical operating center

TABLE III—LARGE WEATHER-PROTECTED MOTORS FOR THE SAM BERTRON STATION

Driven Equipment	No. of Motors	Horsepower	Speed	Voltage	Shaft
Boiler feed pumps	3	2500	3600	2300	Horizontal
Forced draft fans	2	1000	900	2300	Horizontal
Circulating water pumps	2	600	514	2300	Vertical
Condensate pumps	3	200	1800	440	Vertical
Cooling service water pumps	3	125	1800	440	Vertical

those at Deepwater Station which has spare unit.

Piping Protection. Piping in an outdoor plant, even in the Houston area, requires some protection against freezing. This is particularly true of the small lines such as instrument piping.

For this purpose the piping is divided into four categories, as follows:

(1) Lines that reach temperatures of over 500 F;
(2) Lines that reach temperatures of less than 500 F;
(3) Lines that need no additional external heat; and
(4) Lines requiring no protection at all.

In the first group, a $^1/_4$-in. wrap of fire felt is applied, followed by a run of heating cable using one foot of cable to one foot of pipe. This heating cable is installed in 60-ft lengths, equivalent to 400 watts and is supplied by 120-volt circuits. In the earlier installations an asbestos insulated electrical return circuit was used. Present practice is to omit the return circuit and ground each heating circuit to the permanent structure. Aluminum foil is applied over the heating circuit and followed by an overall covering of air cell insulation and outside tarpaper wrapping.

In the second group, lines less than 500 F, the heating cable is run in direct contact with the pipe, which is then wrapped with aluminum foil and covered with the outer insulation.

In the third group, lines needing no additional external heat, no heating cable is used. The pipe is covered only by the conventional magnesium insulation.

The fourth group of piping requires no protection as the service is such as to permit draining.

The heating cable currently being used is No. 19 AWG Nichrome conductor, having a resistance of 0.52 ohms per ft, insulated with fused teflon tape and rated at 1500 volts.

While certain difficulties were encountered on early installations, these have now been largely overcome and operation of the freeze protection system is satisfactory. However, further refinements, expected to result in a more economical installation, are under consideration.

Operating Center. As previously mentioned, present practice is to construct power plants in multiples of two units. Controls for both units are concentrated in one air conditioned control room located between the two boilers and at the operating deck level. The control room is actually the only building included.

The exterior of one of the two operating centers at the Greens Bayou Station is shown in Fig. 4 and is typical of others on the Houston System. Walls are of "Q" paneling; floors are of lightweight concrete fill placed on "Q" decking and surfaced with conventional floor covering; and the roof is a 4-in. concrete slab, insulated and topped with asphalt felt water-proofing. Acoustical tile is used on the ceiling and lighting is provided by fluorescent fixtures suspended above an aluminum eggcrate ceiling 9 ft above the floor level. Emergency incandescent lighting is also provided.

Fig. 5 is an interior view of a typical operating center. The boiler gage boards are at the right and left while the generator control boards are in the background. The load control console is located near the operator's desk.

All boilers and turbine instruments are concentrated within the control room, making it unnecessary to leave the center except for inspections. Duplicate instruments, as required, are located near the boilers and turbines. Remote manually operated controls as well as automatic controls are provided.

Construction

One of the chief factors to be considered in the actual construction of full outdoor plants is the weather conditions which will be encountered. Impediment to construction because of low temperatures is almost nonexistent in the Houston area. Heavy rain squalls, which occur infrequently, do slow down construction; however, this is not altogether peculiar to outdoor plants.

From a construction standpoint the chief advantages of outdoor stations are reduction in time required to construct the station and greater accessibility of equipment.

Irrespective of the relative merits of indoor and outdoor stations it goes unquestioned that elimination of the boiler and turbine-generator enclosures results in shortening of the time required to construct a station. Just how much time is saved varies with the type and size of buildings and structures. Certainly, for a so-called "gold plated" job this saving would be greater than for an indoor station with only the bare necessities in enclosures.

Construction is materially simplified and expedited by placing the major equipment in the open where, for all practical purposes, the working room around the equipment is unlimited. Other factors to be considered are the better light provided by outdoor daylight and the more

TABLE IV—PRODUCTION COSTS AND PERFORMANCE DATA FOR NINE STEAM-ELECTRIC STATIONS* FOR 1954: 300 TO 499 MW

Station Code No.	Total Net Generation, Kwhr × 10^6	Cost of Energy, Mills per Net Kwhr	Max 1-Hr Peak, Mw	Plant Factor, %	Operating Costs, Mills per Net Kwhr: Mtce.	Total Oper. & Mtce. Excl. Fuel	Total Oper. & Mtce. Incl. Fuel	Turbine-Gen.	Total Employees, No.	Peak Mw per Employee	Btu per Gross, Kwhr	Reheat	Principal Fuel†	Station Thermal Eff., %	Avg. Boiler Eff., %
241	2223	6.127	434	88.6	0.075	0.445	2.918	3	119	3.65	8,880	Yes	Coal	36.40	88.60
242	2019	7.109	393	57.6	0.150	0.442	3.644	4	107	3.67	9,298	Yes	Coal	35.24	89.00
243	2046	6.580	400	66.1	0.200	0.440	3.060	6	153	2.61	9,433	Yes	Coal	34.11	90.34
244	2427	7.270	375	86.6	0.140	0.400	3.520	2	61	6.15	9,327	Yes	Oil	35.00	84.70
245	1831	...	334	87.3	0.098	0.369	2.388	3	109	3.06	9,875	Yes	Coal	32.79	89.90
246	1573	...	332	...	0.159	0.489	2.383	3	124	2.68	9,495	Yes	Coal	33.97	88.50
247	2160	3.600	364	79.0	0.141	0.263	1.269	4	79	4.61	11,124	No	Gas	28.80	84.30
248	2212	5.910	328	77.7	0.100	0.330	3.080	3	105	3.12	9,156	Yes	Coal	35.70	90.60
249	1357	5.783	290	68.6	0.175	1.026	4.175	4	101	1.52	11,087	No	Coal	28.90	88.90

* First operation, year, and newest unit, year, shown in Table II for each station. † All stations except No. 247 are equipped with coal-burning facilities. Principal fuel as shown was determined on Btu basis for survey period.
Source of information: Cost and Performance Data of 54 Modern Steam Stations, *Electrical World*, October 17, 1955, pp. 136–139.

agreeable working conditions of outdoor construction. Fig. 2 is a general view of the Webster Station during construction. Trial operation of the No. 1 unit was realized four days after this picture was taken.

Fig. 7 is a photograph taken during the installation of the first 165-mw unit at Sam Bertron Station which illustrates the type of weather-protection used during the installation of the turbine-generator. As a matter of interest, this picture was taken during the latter part of February, yet the temperature is mild as is indicated by the manner in which the workmen are dressed.

Location of the auxiliary switchgear and most of the motors in the open permits a traveling crane to move the equipment to the site and set it directly on the foundation. This is much simpler than indoor construction, which often requires skidding, jacking and "man handling" of the equipment. In general, the simpler and quicker installation of major equipment in the open tends to compensate for the premium paid for it.

Operation and Maintenance

Concentrating all boiler and turbine control equipment for two units in a common operating center results in reduced manpower requirements.

Operating personnel for a two unit station, on the Houston System, consists of four men per shift. These are designated as (*a*) watch engineer, (*b*) control room operator and (*c*) two auxiliary operators. The control room operator and one of the auxiliary operators have fixed posts. The other auxiliary operator makes periodic inspections, taking care of pumps, fans, fuel gas and fuel oil supply and other equipment. The watch engineer, unless engaged in starting of a machine or other routine duties, also makes outside inspections and checks conditions with the auxiliary operator. Under the abnormal conditions of oil firing, a fifth man is required. The addition of the third and fourth units to a station with their common control room necessitates only three more operators per shift, as the outside auxiliary operator takes care of all four units. Although a smaller crew is required to operate an outdoor station than a conventional indoor station, it is recognized that part of this advantage, at least on the Houston System, results from the use of natural gas rather than a solid fuel. In some localities personnel requirements may be affected also by union agreements.

In addition to the strictly operating personnel there are, of course, maintenance, supervisory and clerical forces and guards. The number of maintenance employees charged to any individual plant will vary with the work to be done at that particular station.

On the Houston System, maintenance expenses for two indoor stations with a total rated capacity (MMRC) of 392 mw averaged 0.486 mills per kwhr for the five-year period 1951 through 1955; for the same period, three outdoor stations with a total rated capacity (MMRC) of 757 mw averaged 0.126 mills per kwhr. These costs may not be strictly comparable since the indoor plants are considerably older than the outdoor stations, but this would hardly account for the great difference in favor of the outdoor stations.

Further comparison of the nine Group VIII stations drawn from Reference (1), as shown in Table IV, tends to strengthen the position of the outdoor station. While the full outdoor, gas-fired station No. 247 had the fifth highest maintenance cost, it had the lowest total operating costs excluding fuel, as well as the lowest including fuel. It had the second lowest number of employees and

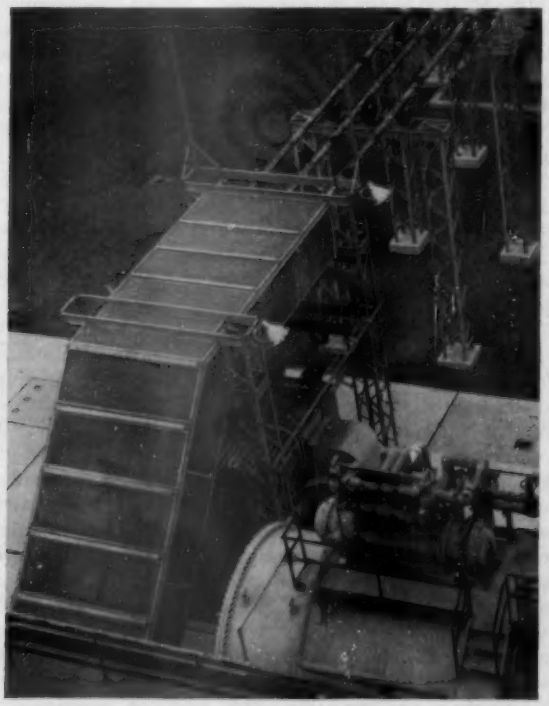

Fig. 6—Open-type generator leads and protective enclosure near the operating deck

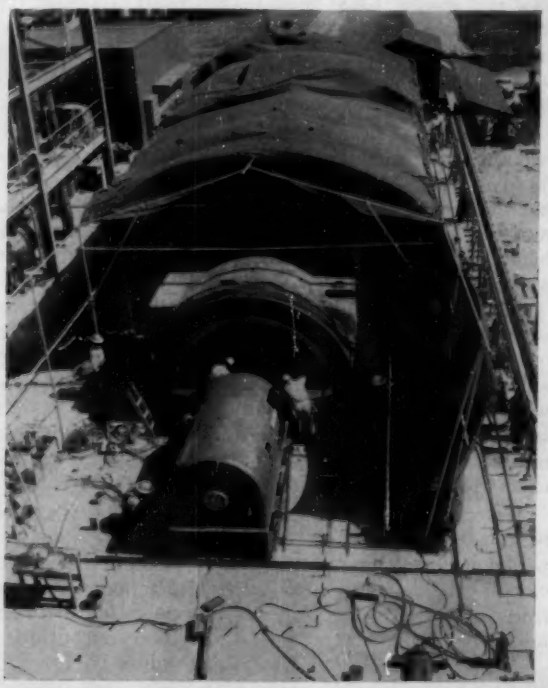

Fig. 7—Portable tarpaulin canopy used during the installation and maintenance of turbine-generators

was second highest in mw of peak per employee. This favorable showing is made in spite of the fact that on gas fuel (with its inherent hydrogen loss) it had the highest heat rate and the lowest thermal and boiler efficiencies of the nine stations. These comparison seem to confirm the overall economic advantage of outdoor stations as built and operated on the Houston System.

In a comparison of outdoor and indoor plants one of the chief points of interest is the operation and maintenance of motors. Since the Houston System was among the pioneers in outdoor plant construction it may be of interest to review briefly some of its earlier experiences.

When, in 1943 and 1947, the first two units utilizing outdoor motors were completed at Hiram O. Clarke Station, weather-protected motors, as they are known today, were not available. At this installation the four boiler fans and their 2300-volt motors for both units were located entirely outdoors as was the circulating pump and its motor for the 1947 unit. These five motors were specified to be splash-proof, suitable for outdoor operation. However, this design proved inadequate and six failures, all due to moisture, occurred on four of the motors before modifications were made. As supplied, the ventilating air was drawn through a short downward extension of the lower half of the end bell, which permitted the entrance of moisture. Installation of redesigned and improved end bells, furnished by the manufacturer, along with other changes has resulted in improved and satisfactory operation.

Trouble was again experienced with outdoor motors when the first two units at the Greens Bayou Station went into service in April and August, 1949. These motors were purchased during the postwar period when deliveries, even on standard equipment, were long and many times indefinite. Accordingly, conventional splash-proof boiler fan motors were purchased with the thought that rain shields would be added to the air intakes in the field. Because of the urgent need for additional generation and the press of other construction work, the first unit was placed in operation utilizing the fan motors before the rain shields were installed.

The plant had been on the line less than 24 hr when it was subjected to a rain storm accompanied by winds of 50 to 55 mph. Within 20 min. three of the four fans serving the boilers were lost due to water getting into the motors. Fortunately, motors for the second unit were on hand, permitting a quick change-out and restoration of service within 12 hr.

Subsequent examination of the damaged motors revealed that the varnish treatment of the coils was inadequate and that air velocities in the intake openings approached 1500 fpm which is sufficient to carry solid water into the motor windings. These deficiencies were corrected and no further trouble due to moisture has been experience with these motors, even during a near hurricane with heavy rains and winds 65 to 70 mph.

Motor failures at Hiram O. Clarke and Greens Bayou Stations just described, characterize the development period of the modern weather-protected motor, which became available about 1950. This development resulted from field experience and close cooperation between motor manufacturers, consulting engineers and utilities.

Completion of the third and fourth units at Hiram O. Clarke Station in 1950 and 1951 marked the initial installation of large 2300-volt motors of the modern weather-protected design. These motors are of the base ventilated type, featuring low intake air velocities and an improved arrangement of air intake, distribution and discharge. No trouble which can be attributed to outdoor installation and operation has been experienced with these motors or with the outdoor turbine-generators to date, although a number of unscheduled outages have resulted from such troubles as breakdown of coil insulation to ground, softening of mica insulation, tape separation, exciter vibration and similar causes.

Weather-protection, when necessary in the performance of maintenance work, is obtained by placing over the unit a tarpaulin canopy similar to that used during initial installation and illustrated in Fig. 7. Such protection was employed when the Greens Bayou No. 1 generator failed due to migration of stator coil insulation at the beginning of the longest sub-freezing period of record. Sub-freezing temperatures persisted for 120 hr, during most of which time sleet and freezing rain fell. To locate the trouble it was necessary to remove the exciter and pull the generator field. The greatest difficulty encountered during the adverse weather was in keeping the gantry crane in operation, as ice formed on the trolleys and wires, interrupting the 440-volt service to the crane motors. While this was a major outage, requiring nearly a month for repairs, it is estimated that the work was delayed only half a day due to adverse weather conditions. This experience, which can reasonably be assumed to represent the worst conditions, demonstrated that even unusual problems can be surmounted.

Scheduled Maintenance

The annual load curve of the Houston System is characterized by high loads during the summer, with the peak normally occurring during the month of August. This is primarily due to the wide acceptance of air conditioning. Accordingly, major inspection and maintenance is scheduled for fall, winter and spring months. Inspection of the smaller units is usually started in October. Larger units are removed from service during the period of November to mid-April. An effort is made to complete all inspections by the middle of May.

Actually, fall and spring are the best months for outdoor work in South Texas. Even in the winter, a majority of the days are fair and of moderate temperature. The prolonged heat in the summer wears down the workers and shelter from the hot sun is necessary for the most efficient working conditions. The winter cold usually comes in short spells as a result of "Northers" which may be accompanied by rain. With adequate clothing against the cold and rain and with some shelter or wind break, the work may be carried on satisfactorily. In the case of small jobs, protection is provided by a trapaulin temporarily stretched, but for turbine-generator work the portable canopy shown in Fig. 7 is used. Even under very adverse weather conditions, the work proceeds with as much dispatch and efficiency as it does in the numerous unbearably hot places about the usual indoor plant. Superintendents and supervisors believe that the open arrangement allows better general supervision of activities, and operators and maintenance men prefer working at the outdoor stations.

Experience with the outdoor plant has been too short to estimate the probable extra costs of maintenance painting. All paints "weather" under the action of sun,

wind and rain. This is particularly true on hot surfaces. On unlagged blowdown and vent piping and boiler breechings, nothing really satisfactory has yet been found. It seems desirable, for appearance and economy, to lag such lines. To maintain turbine appearance, annual spray painting is required while boiler casings can go three to four years. Absence of building and roof maintenance in an outdoor plant tends to offset the extra painting required by outside equipment.

Safety

The safety record in both construction and operation of outdoor plants on the Houston System has been very good and compares favorably with that of indoor plants.

From the standpoint of personnel, certainly, an outdoor plant is safer than an indoor plant in case of fire or explosion. In the outdoor plant personnel is not subjected to the hazard of falling or crumbling walls nor to the additional hazards created by flying or falling objects within a building. On the other hand, maintenance work carried on outdoors during adverse weather conditions, as during ice storms, is perhaps more hazardous.

In modern times, there has not been a major explosion or fire at any generating plant, whether of the outdoor, semi-outdoor or indoor type. Accordingly, one type of plant has just as good a record as another. In spite of this record it is felt that, inherently, the outdoor plant is the safer risk. This is confirmed by fire insurance rates.

At the Hiram O. Clarke Station the fire insurance rate for the two semi-outdoor units is $0.04 per $100 valuation, while for the two full outdoor units the rate is $0.01. At the Gable Street Station which is completely indoors, except for the semi-outdoor extensions, the corresponding rate is $0.05 per $100. Thus it appears that the chances of a destructive fire in an indoor plant are rated 4 to 5 times as great as in an outdoor plant.

Reserve Capacity

The type of plant, that is outdoor, semi-outdoor or indoor, is not considered when determining reserve generating capacity for the Houston System. Present practice is to set-up as system reserve generating capacity, an amount equal to the capability of the largest single unit on the system. Presently, this amounts to 165,000 kw, which is about 11.5 per cent of net generating capability.

Depreciation

Because of the relatively short service record of full outdoor stations on the Houston System, actual life expectancy figures are not available for outdoor plant facilities. However, up to the present time, there has been no evidence that life expectancy of outdoor equipment is any different from that of indoor equipment.

Conclusions

Experience of Houston Lighting & Power Company in the installation and operation of outdoor steam-electric generating stations leads to certain conclusions as to the relative merits of outdoor and indoor plants.

1. Construction costs for outdoor stations are less than for conventional indoor stations, the difference amounting to about $10 per name plate kw on the Houston System.

2. Electrical equipment suitable for outdoor operation is now available at a premium in price. At the Sam Bertron Station this amounted to about $0.96 per kw for the principal items which is relatively minor in comparison with the total saving available.

3. Construction time is less for the outdoor plant because of the elimination of buildings, the more compact arrangement of equipment and the greater accessibility.

4. Although maintenance costs, in some cases, are higher for outdoor than for indoor plants, total operating and maintenance costs of outdoor stations compare favorably with those of indoor plants.

5. Personnel requirements, on the Houston System, are less for outdoor plants and both operating and maintenance personnel prefer working conditions there.

6. Safety records at both outdoor and indoor stations are excellent. However, the safety engineers do agree that the outdoor plant offers greater safety to personnel. Moreover, insurance rates indicate that there is less likelihood of a destructive fire at an outdoor station.

7. Thus far there is no indication of any difference in required reserve generating capacity or in life expectancy of power plant equipment for outdoor and indoor generating stations.

8. Experience points toward the continued construction of full outdoor stations on the Houston System.

REFERENCES

(1) 9th Steam Station Cost Survey. *Electrical World*, New York, N. Y., Vol. 144, No. 16, October 17, 1955, pp. 127–146.

(2) Deepwater Extension—165,000 KW, A. P. Priddy. *Southern Power and Industry*, Atlanta, Ga., and Charlotte, N. C., Vol. 74, No. 1, January 1956, pp. 40–46.

(3) Application of Equipment in Outdoor Steam-Electric Generating Stations, W. D. Marsh, A. G. Mellor. *AIEE Transactions*, Vol. 74, 1954, pp. 1294–1300.

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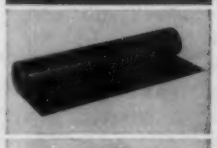

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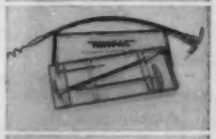

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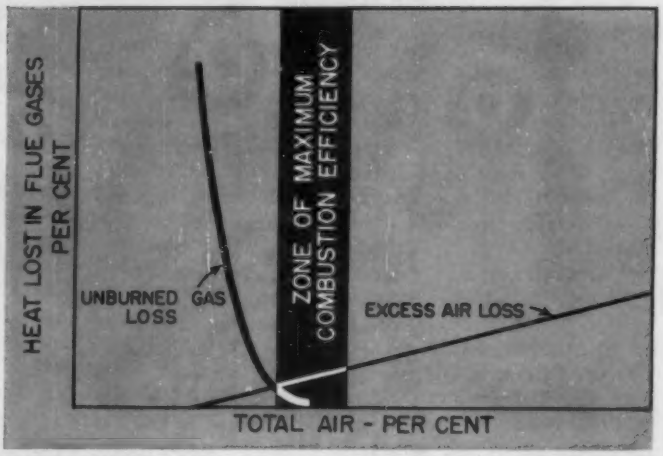
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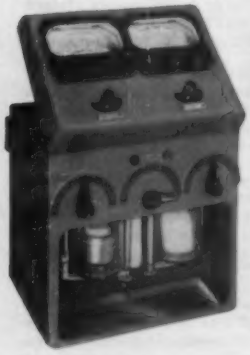

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Bubble Contact Heaters for Power Plants*

By GEORGE P. KOTELEWSKIJ

The recent decisions to go to supercritical pressure boiler cycles has stimulated a review of thermodynamic fundamentals covering the major elements in the cycle. Here is an interesting report on the bubble contact heater for feedwater heating as contrasted to the tubular design.

BOILER feedwater usually is heated by exhaust steam, or steam bled from somewhere in the power plant cycle, except where economizers, which utilize flue gas, are used. Tubular heaters, with water on the tube side, are by far the most common type of heat exchange equipment employed in modern power plants. The use of direct contact heaters, on the other hand, probably has been retarded because of lack of sufficient data needed to make an intelligent engineering and economic comparison.

During the early years of power plant development, direct contact heaters were conceded to be relatively inefficient at low steam pressure, even though they offer several advantages uncommon to tubular heaters. Direct contact exchangers suffer no loss in temperature head, if an initial steam pressure is maintained in the apparatus and water is heated to the saturation temperature of the steam in the exchanger. In tubular heaters, however, the exit water is generally 2 to 12 F below the saturation steam temperature in the exchanger. Scale accumulation is always a problem. Direct contact heaters offer another important advantage over tubular heaters—they provide feedwater deaeration and a convenient receiver for condensation of steam from various sources.

Two different types of direct contact heaters could be employed—the jet exchanger or the bubble exchanger. Jet contact heaters may be ruled out by cursory examination because they require a large steam chamber into which water is sprayed, and high-pressure chambers are expensive. Even at low pressures, difficulties are encountered both in the counterflow of water across the trays or pans and in the exhaust of noncondensed steam. Spray nozzles can be used instead of pans to distribute the water, but this procedure does not circumvent the other difficulties.

Bubble contact heaters, where high-pressure steam is injected into the water, have none of the disadvantages inherent in the jet exchanger. They do not require special deaeration equipment and condensate coolers, which are also required by high-pressure tubular heaters.

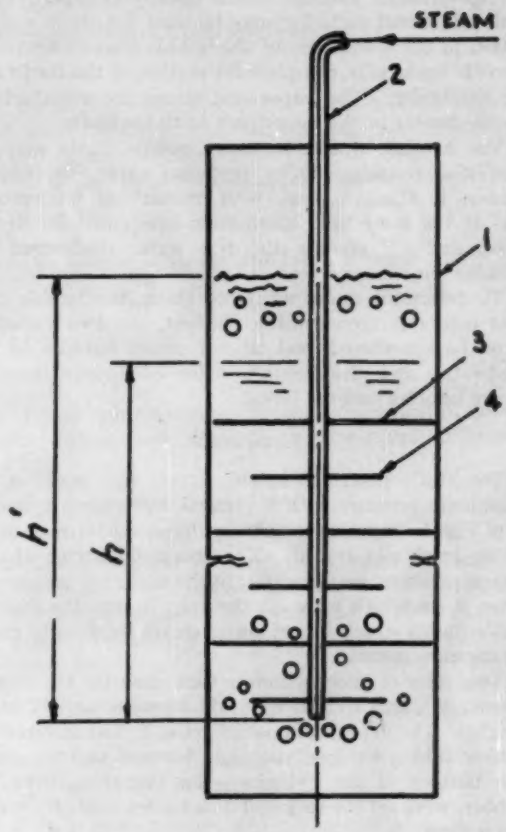

Fig. 1—Laboratory bubble contact steam condenser

At high steam pressures (above 120 psia), bubble contact heaters are more economical than tubular heaters because of their smaller size and simpler construction. Cheaper materials of construction may be employed because the bubble contact heater operates at saturated steam temperature, rather than at superheated steam temperatures.

The high-pressure tube heaters in the last stage of the heating system may be replaced by bubble contact heaters. Consequently, the feed pump, which must be provided for necessary submergence, is displaced after the bubble contact heater. This pump usually is placed before the last stage of the tube heaters.

The proposed apparatus consists of a vertical closed cylinder, with an upper nozzle for feedwater inlet and a bottom nozzle for feedwater outlet. The water level in this apparatus is automatically maintained near the upper nozzle by a regulator. Steam enters at the lower part of the apparatus and flows countercurrently upward through the column of water. Disk-and-ring-

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toothed baffles, attached to the inside of the cylinder, provide a zigzag path for the steam bubbles. These baffles increase the effective length of the equipment and break up the steam bubbles. Air carried into the system with the entering steam is vented through a nozzle at the top of the heater. The control of the air outlet allows the pressure in the projected bubble contact heater to be maintained in order to obtain the maximum saturation temperature of the feedwater.

High-pressure exhaust steam usually is superheated. This additional enthalpy may be used for some evaporation in the lower part of the bubble contact heater to provide essentially complete deaeration of the feedwater for the boiler. The vapor and steam are absorbed by the feedwater in the upper part of the cylinder.

The heating system in many power plants may be simplified considerably by replacing expensive tubular heaters in the last stage with bubble contact heaters, and at the same time eliminating equipment for deaeration and for cooling the hot water discharged by tubular heaters.

To determine under what conditions the bubble contact heater is economically efficient, the two variables must be considered—velocity of steam bubbles in the feedwater and the heat transfer coefficient between steam bubbles and the liquid.

Equipment

The study described in this article was made at atmospheric pressure with a vertical, open glass cylinder, *1*, of Fig. 1, on which a scale (millimeters) for measuring water level was traced. The steam, at about atmospheric pressure, was driven into the water by means of a tube, *2*, on which were set the ring, *3*, and the disk, *4*, baffle plates which forced rising steam bubbles to make zigzag movements.

Two sizes of glass cylinders were used for the experiments, $3^3/_4$ and $1^7/_8$ in. in inside diameter and 12 in. in height. The $^1/_4$-in. aluminum tube, *2*, was covered by rubber tubing for insulation and lowered to 1 in. above the bottom of the cylinder. On the tube, over the rubber, were set the ring and disk baffles made from thin brass sheet.

In the $3^3/_4$-in. cylinder, four ring (3.72 in. in outside and 1.38 in. in inside diameter) and four disk (2.95 in.) baffles were placed. The distance between baffles was 0.617 in. The lowest disk was fixed at the end of the tube, and the total baffled height was 4.33 in.

In the $1^7/_8$-in. cylinder, two ring (1.85 in. in outside and 1.0 in. in inside diameter) and two disk (1.4 in.) baffles were used. The distance between baffles was 1.6 in. and the total baffled height was 4.8 in.

The steam was generated in a closed pot, approximately 0.5 gal capacity, with $^1/_4$-in. steam outlet and $^1/_2$-in. relief valve. The steam nozzle was connected with the aluminum tube, *2*, by rubber tubing.

A mercury thermometer (deg C) was placed in the lower part of the cylinder and extended into the mixture of water and steam bubbles. Actually, the temperature of the water was measured. The glass cylinder was not insulated.

Procedure

Water was boiled in the pot with the relief valve open. When the valve was closed, steam entered the water in the glass cylinder through the aluminum tube.

While the steam was rising in the water, all or a part of it was condensing, and, at the same time, the temperature of the water and the level of the mixture in the cylinder were changing.

The following data were recorded:

Time
Temperature of water
Height of mixture (water and steam bubbles)
Height of water only (for this measurement the steam flow was stopped for a moment by opening the pot relief valve)

The following is a sample of recorded data (Test 1 of Table I):

Time, min	t_w, °C	h, mm	h', mm	Calcd. Δt = 100 − t_w, °C
0	56	149	150	44
1	68	...	152	32
2	75	155	...	25
3	81	...	158	19
4	87	159	161	13
Mean		154.3	155.2	26.6

Growth of water in cylinder

$$\Delta h = \frac{159 - 149}{4} = 2.5 \text{ mm/minute}$$

These data are sufficient for the calculation of velocity of steam bubbles and the coefficient of heat exchange.

In the experiments on the determination of steam bubble velocity, Δh first was defined by full steam ab-

TABLE I—HEAT TRANSFER FROM STEAM BUBBLES TO WATER IN 1 ATMOSPHERE ABSOLUTE

Test No.	Changes in Temp of Water, °C From	To	Time of Test min	Δt, °C	h', mm	h, mm	$h' - h$, mm	Δh, mm/min	b, % (Eq. 5)	Heat Transfer Coefficient $-q$, Btu/(sq ft) (hr) (° F) (Eq. 15)	Deviation, %
					$3^3/_4$-In. Glass Cylinder, ϵ = 2.55						
1	56	87	4	26.6	155.2	154.3	0.9	2.5	0.6	210,000	103
2	68	94	4	19.8	142.5	141	1.5	3.5	1.0	240,000	118
3	95	99	4	3.0	163	154.5	8.5	2.5	5.5	200,000	98
4	91.5	99	3	4.0	176.5	167	9.5	2.65	5.4	140,000	69
5	90	100	2	5.0	179.5	168.5	11.0	3.5	6.2	130,000	64
6	65	84	3	24.8	156	155.2	0.8	2.5	0.5	260,000	128
7	81	96	2	10.0	164	161.5	2.5	2.5	1.5	200,000	98
8	92	98	1	4.3	172	168	4.0	2.0	2.3	230,000	113
9	97	99	1	2.0	181.5	170	11.5	2.0	6.3	180,000	88
10	61	88	3	25.5	142.5	141.2	1.3	3.7	0.9	220,000	108
11	80	94	3	12.5	128.5	126	2.5	2.7	2.0	170,000	83
12	96	100	2	2.0	176.5	156.5	20	3.5	11.4	180,000	88
					$1^7/_8$-In. Glass Cylinder, ϵ = 0.25						
13	61	92	3	23.5	156	154.2	1.8	5.1	1.1	240,000	118
14	75	98	3	13.0	163	160	3.0	4.6	2	230,000	113
15	78	94	1	14.0	159	155.2	3.8	6.5	2.4	240,000	118
16	50	99	2	19.8	149	144	5.0	12	3.3	240,000	118
17	55	98	2	22.0	145.6	140	5.6	11	3.8	180,000	88
18	68	93	3	19.5	141.5	139.5	2.0	4.3	1.4	220,000	108
19	55	99	2	23.0	142	137	5.0	5	3.5	160,000	79
										203,000 (av.)	100 (av.)

sorption at a constant steam generation, and the cross-sectional area steam velocity in the cylinder at 100 C was calculated by the formula:

$$u_0 = 2.78\Delta h \text{ cm/second} \quad (1)$$

Bubble Velocity in Water

The volume of the steam bubbles in water at any moment is $(h' - h)a$ and the time the steam bubbles remain in the heater is

$$\tau = \frac{h' - h}{v} \quad (2)$$

The average velocity of steam bubbles rising in the water is

$$u' = \frac{h'}{\tau} \quad (3)$$

Linear steam velocity in the cylinder is

$$u = \frac{v}{a} \quad (4)$$

The volume percentage of steam bubbles in the mixture is

$$b = \frac{100(h' - h)}{h'} \quad (5)$$

The coefficient, b, is the bubbling coefficient. From Eqs. 3, 4, and 5,

$$u' = \frac{100u}{b} \quad (6)$$

The velocity, u', measured in this integral way is really the average velocity of bubbles rising in the liquid (2).[1]

It is known that the velocity of a gas bubble in liquid is inversely proportional to the kinematic viscosity of liquid; bubble velocity increases with the size of the bubble and decreases with surface tension. In the following calculation the effect of the viscosity of water on steam bubble velocity is considered, with other factors, such as diameter of bubbles and surface tension of water, assumed to be unchanged.

On the basis of the Stokes equation of ball resistance (4) and the data of O'Brien and Gosline for bubble velocity in tubes (3),

$$U' = \frac{c}{\nu} \quad (7)$$

In Eq. 7, c, which includes all other factors, is assumed as a first approximation to be constant. The average velocity of bubbles rising in water is dependent on the length of the zigzag movement. The length of the zigzag path (Fig. 2) is

$$L = N(D_2 - D_1) + H_b \quad (8)$$

where the baffled height of the column is $H_b = NZ$. Bubble path elongation on one unit of baffled height is

$$e = \frac{N(D_2 - D_1) + NZ - NZ}{NZ} = \frac{D_2 - D_1}{Z} \quad (9)$$

Eq. 9 may be considered to represent a baffle characteristic. It shows how the baffles (ring and disk) elongate the path of bubbles in water. The path elongation in the $3^3/_4$-in. glass cylinder was

$$e = \frac{2.95 - 1.38}{0.617} = 2.25$$

and for the $1^7/_8$-in. cylinder,

$$e = \frac{1.4 - 1.0}{1.6} = 0.25$$

Absorption of Steam Bubbles in Water

For finding the heat transfer coefficient at the direct contact of steam with water, the following formulas were used:

The absorption of steam in a cylinder is

$$a\Delta h\rho_w$$

If the average diameter of the bubbles is known, the coefficient of absorption and heat transfer per unit of contact surface may be calculated.

Total surface of bubbles in water at any moment is

$$s = n\pi d^2$$

Since the volume of steam bubbles in water is $a(h' - h)$,

$$n = \frac{a(h' - h)}{{}^1/_6\pi d^3} \quad (10)$$

$$s = \frac{6a(h' - h)}{d} \quad (11)$$

The coefficient of steam absorption per unit of steam bubble surface and degree of temperature difference would be

$$\alpha = \frac{a\Delta h\rho_w}{s\Delta t} \quad (12)$$

As it is difficult to measure the average diameter of bubbles in the water (a part of them unite in streams), it is preferable to define the coefficient of absorption as the weight of absorbed steam per unit volume of steam bubbles in water.

$$\beta = \frac{a\Delta h\rho_w}{a(h' - h)\Delta t} = \frac{\Delta h\rho_w}{(h' - h)\Delta t} \quad (13)$$

Accordingly, the heat transfer coefficient of 1 atmosphere steam bubbles in water is

$$k = \frac{540 \times 60 \times 10^6\beta}{1000} = \frac{32.4 \times 10^6\Delta h\rho_w}{(h' - h)\Delta t} \quad (14)$$

or, in the English system,

$$q = \frac{2.02 \times 10^6\Delta h\rho_w}{(h' - h)\Delta t} \quad (15)$$

TABLE II—STEAM BUBBLE VELOCITY AT 1 ATMOSPHERE ABSOLUTE IN WATER AT 100 C

Test No.	h', mm	h, mm	b, % (Eq. 5)	Bubble Velocity u', cm/sec (Eq. 6)	Bubble Velocity U'_0, ft/sec	Steam Velocity u_0, cm/sec (Eq. 1)	Steam Velocity U_0, ft/sec
			$3^3/_4$-In. Glass Cylinder, e = 2.55				
1	140	131.5	6.1	59	1.94	3.6	0.118
2	147	132	10.2	63	2.06	6.4	0.210
3	152	131	13.8	60	1.96	8.3	0.272
4	140	120	14.3	64.3	2.11	9.2	0.302
5	204	165	19.0	63.7	2.09	12.1	0.397
6	230	200	15.0	73	2.39	11.0	0.360
7	192	172	10.4	71	2.33	7.4	0.242
8	210	175	16.7	58.5	1.92	9.75	0.320
9	188	171	9	77	2.53	6.95	0.228
			$1^7/_8$-In. Glass Cylinder, e = 0.25				
10	214	199	7.0	71.5	2.35	5.0	0.164
11	207	173	16.4	79.3	2.80	13	0.426
12	220	194	11.8	76.3	2.50	9.1	0.298
13	210	172	18.5	77	2.53	14.3	0.469
14	230	170	26	77.5	2.54	20.2	0.662
15	226	174	23	71.0	2.33	16.3	0.535
16	215	150	30.2	82.8	2.71	25	0.820
17	225	154	31.6	96.5	3.17	30.6	1.00
18	230	157	31.8	105	3.45	33.4	1.095

[1] Numbers in parentheses within the text refer to the Bibliography at the end of the article.

The relation between the volume and surface coefficients of heat transfer is

$$q_s = \frac{q d_i}{71.5} \qquad (16)$$

where d_i is the average diameter of bubbles in inches. The diameter of the cylinder is not required for calculations and the relation, $h/h' = h$, does not depend on the dimensions of the apparatus.

Results of the experiments are in Tables I and II.

The resultant heat transfer coefficient, $q = 203{,}000$ Btu per (cu ft) (hr) (deg F) (average of 19 tests), is estimated per cubic foot of steam bubbles at 1 atmosphere absolute in water. In order to calculate a coefficient based on 1 sq ft of bubble contact surface, the average diameter of the steam bubbles, which is difficult to measure, must be known. From observation, bubbles appeared to be approximately $^1/_2$ to 1 in. in diameter, but a part of them had united in streams. By assuming the average diameter of bubbles to be 0.75 in. the heat transfer coefficient per square foot of bubble surface (Eq. 16) is

$$q_s = \frac{203{,}000 \times 0.75}{71.5} = 2100$$

Compared with the Nusselt film coefficient, a greater rate of heat transfer by direct contact of steam with water might be expected. However, because the union of bubbles and the average diameter of bubbles cannot be discounted, the coefficient of heat transfer per cubic foot of steam bubbles estimated above is used in the present calculations. It is expected that q would increase with increased steam pressure.

It is also expected that the velocity of bubbles in water would be somewhat greater in the industrial bubble contact heater than in the pilot cylinders. (For instance, in the small glass cylinder, $1^7/_8$ in. in diameter, the wall friction might affect the steam bubble velocity.)

As the average velocity of bubbles rising in water depends on the baffling, the velocity could be slowed by zigzag path elongation, but the velocity in a vertical direction cannot be increased mechanically. Calculations for an exponential curve (Fig. 5) that shows the diameter of bubble contact heater as a function of the steam pressure were based on the steam velocity at 100 C. and 0.295 cs kinematic viscosity of water. The influence of water column velocity, in counterflow in a bubble contact heater, is assumed to be negligible.

The bubbling coefficient is a very important coefficient in calculations of bubble contact apparatus. According to the tests, the average bubbling in a vertical cylinder should not exceed 25 to 27 per cent to prevent the formation of bubbles in great streams and decreasing of contact surface between bubbles and liquid. Table II and Fig. 3 show that the bubbling is approximately proportional to the cross-sectional area steam velocity. The steam bubble velocity, however, remains almost constant as the bubbling coefficient increases to approximately 25 per cent, as shown in Fig. 4. This result might be expected, according to Eq. 6. If b is proportional to u

$$b = c_1 u \qquad (17)$$

then

$$u' = \frac{100u}{b} = \frac{100u}{c_1 u} = \frac{100}{c_1} = \text{constant} \qquad (18)$$

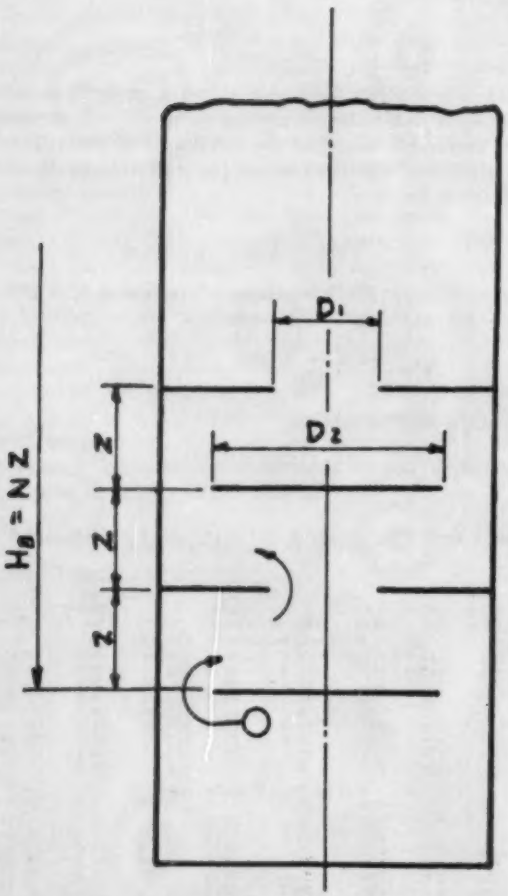

Fig. 2—Disk and ring baffle system for bubble contact heater

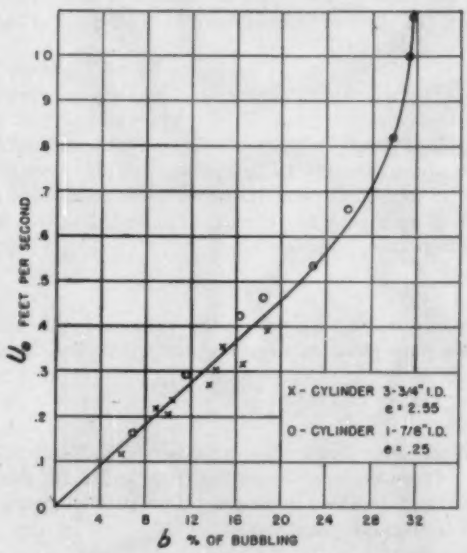

Fig. 3—Cross-sectional steam velocity in water at 100 C

This result does not agree with the assumption of Geddes (1) that the bubble velocity is proportional to the height of the mixture.

The average steam bubble velocity in water at 100 C was found to be $U_0' = 2.25$ fps. From the permissible bubbling, $b = 25$ per cent, maximum linear steam velocity for the bubble contact heater may be determined (Eq. 6).

$$U_0 = \frac{bU_0'}{100} = \frac{25 \times 2.25}{100} = 0.57 \text{ fps}$$

As the bubbling coefficient increases to over 25 per cent, the bubble velocity evidently increases, because of union of bubbles into the steam streams.

Hammering

Fear has been expressed concerning possible hammering produced by driving high-pressure steam into water. It may be supposed that steam hammering is the result of kinetic energy strokes of water that rushes into the steam bubbles as a consequence of the steam absorption. This can be calculated. From the general equation of absorption, the volume velocity of absorption for a steam bubble is

$$\frac{dv_b}{d\tau} = \frac{\alpha(t_{st} - t_w)4\pi r^2}{60\rho_{st}} \tag{19}$$

The volume of a bubble is $v_b = 4\pi r^3/3$. By differentiation,

$$\frac{dv_b}{d\tau} = 4\pi r^2 \tag{20}$$

From Eqs. 19 and 20, the linear velocity of water in a radial direction into the steam bubble is

$$u_w = \frac{dr}{d\tau} = \frac{\alpha(t_{st} - t_w)}{60\rho_{st}} \tag{21}$$

The energy of hammering when a mass of water rushes into the condensing steam bubble will be proportional to kinetic energy

$$E = \frac{c_2 m u_w^2}{2} \tag{22}$$

The mass of water is proportional to the volume of steam bubble

$$m = \frac{4\pi r^3 \rho_w}{3} \tag{23}$$

From Eqs. 21, 22, and 23

$$E = \frac{c_2 \pi \rho_w r^3}{90}\left[\frac{\alpha(t_{st} - t_w)}{\rho_{st}}\right] \tag{24}$$

Eq. 24 shows that energy of hammering depends on the radius of a steam bubble and on the temperature difference between steam and water. In the experiments, the temperature of water was changed at intervals from 20 to 100 C, but the temperature of steam was constant at 100 C (1 atmosphere). The hammering took place in water to 45 to 47 C. and quieted down when the temperature of the water was above 50 C. At high pressure the density of steam will increase in the denominator more than the temperature difference in the numerator of Eq. 24. (In the case of superheated steam the coefficient of absorption, α, will be lower than that of saturated steam.) Therefore, there is no reason to expect trouble in high-pressure bubble contact heaters because of hammering.

On the basis of the above experiments and considerations, the following formulas for calculations of bubble contact heater apparatus may be developed.

From the experiments the vertical average "bubbling" data in the cylinder were found; therefore, for calculations of bubble contact heater diameter, on the basis of these data, the vertical average cross-sectional area steam velocity should be used. If it is assumed that all the steam (except for the air) in bubble contact heater is condensed, for the vertical average steam velocity,

$$U = \frac{V + V_a}{2A} \tag{25}$$

According to Eq. 6, $U = bU'/100$ in water at 100 C, $U_0 = bU_0'/100$

According to Eq. 7,

$$U' = c/\nu/U_0' = c/\nu_0$$

hence

$$U' = \frac{U_0'\nu_0}{\nu} \tag{26}$$

From Eqs. 6, 25, and 26 the cross-sectional area of the cylinder is

$$A = \frac{(V + V_a)\nu}{2\nu_0 U_0} \tag{27}$$

Where ν_0 is the kinematic viscosity of water at 100 C and is equal to 0.295 cs. Hence, the diameter of bubble contact heater, in inches, is

$$D = 12\sqrt{\frac{(V + V_a)\nu}{2 \times 0.785 \times 0.295 U_0}} = 17.65\sqrt{\frac{(V + V_a)\nu}{U_0}} \tag{28}$$

The test data for U_0 are from Fig. 3, according to assumed b.

Reaction Space

According to the definition of the heat transfer coefficient (Eq. 15),

$$R = \frac{100Q}{q\Delta Tb} \tag{29}$$

Minimum vertical height of reaction space is

$$H' = \frac{1728R}{0.785D^2} = \frac{2200R}{D^2} \tag{30}$$

The dimensions of the bubble contact heater depend on the two principal factors—steam bubble velocity in water and steam absorption (or heat transfer coefficient). These experiments allow the conclusion that, at low steam pressure, the size of the bubble contact heater is not limited by steam absorption, but by bubble steam velocity. At low steam pressure, tube heaters are more effective than bubble contact heaters. Calculated data for a bubble contact heater may be compared with the following data for a low-pressure tube heater:

	Flow Rate (G), lb/hr	Pressure (P), lb/sq in. abs	Temp (T), °F
Superheated steam inlet	74,510	53.9	555.7 (285.8 satd.)
Drain inlet (condensate)	326,760		293.8
Feedwater inlet	1,500,000		214.3
Feedwater outlet			283.8
Mean temperature difference, ΔT			16.1

The heat to be exchanged (by condensing plus desuperheating) is equal to Q = 81,300,000 Btu per hr.

The tubular heater required would have a shell diameter of 56 in. and U-tubes 232 in. long.

For the same conditions of heat exchange, the volume of inlet steam is

$$V = \frac{74{,}510 \times 12.0}{3600} = 248 \text{ cfs}$$

where 12.0 is the specific volume of superheated steam in cubic feet per pound at $T_{st} = 555.7$ F and $P = 53.9$. Kinematic viscosity of water at 285.8 F (assumed to be the temperature of saturated steam) is $\nu = 0.202$.

At a bubbling of 20 to 22 per cent, from Fig. 3, $U_0 = 0.49$ fps, and from Eq. 28, the diameter is

$$D = 17.65 \sqrt{\frac{248 \times 0.202}{0.49}} = 179 \text{ in.}$$

(In this calculation the volume of air is assumed to be negligible.) The space (from Eq. 29) is

$$R = \frac{81{,}300{,}000}{203{,}000 \times 16.1 \times 0.20} = 124$$

and the minimum reaction space height (from Eq. 30) is

$$H' = \frac{2200 \times 124}{179^2} = 8.5 \text{ in.}$$

A cylindrical apparatus with $D = 179$ in. and $H' = 8.5$ in. appears strange and deformed. These calculations demonstrate why bubble contact heaters have appeared to be inefficient at a relatively low steam pressure. They also show that bubble contact heaters may have more advantages as the steam pressure rises above 110 to 120 psia. Another example may illustrate this more clearly.

A tubular heater with a 36-in. inside diameter shell and 270-in. U-tubes is designed for a steam inlet rate $G = 36{,}000$ at $P = 317.7$ and $T_{st} = 560$ F (422.6 F saturated), with a heat exchange $Q = 35{,}000{,}000$ at $\Delta T = 17$ F. These figures are representative of the operation of tubular heaters. Accordingly, $v = 18$ and $\nu = 0.131$.

For a bubble contact heater under these same conditions of operation,

$$D = 17.65 \sqrt{\frac{18.0 \times 0.131}{0.49}} = 38.7 \text{ in.}$$

$$R = \frac{34{,}000{,}000}{203{,}000 \times 17 \times 0.20} = 50.7 \text{ cu ft}$$

$$H' = \frac{2200 \times 50.7}{38.7^2} = 73.5 \text{ in.}$$

TABLE III—DESIGN OF BUBBLE CONTACT HEATERS

G = 36,000 lb/hr
Q = 35,000,000 Btu/hr
ΔT = 17 F
q = 203,000 Btu/(cu ft) (hr) (° F.)
b = 20 to 22 per cent
U_0 = 0.49 fps

Steam Press. (P), lb/sq in. abs	Steam Temp (T), ° F	Kinematic Viscosity of Water (ν), cs	Specific Vol. of Steam (v), cu ft/lb	Vol. of Inlet Steam (V), cfs	Diameter (D), In. (Eq. 28)	Height (H'), in. (Eq. 30)
10	193.2	0.31	38.4	384.0	276.0	1.47
20	227	0.28	20.0	200.0	190.0	3.10
40	267.2	0.225	10.5	105.0	123.0	7.43
60	292.7	0.194	7.1	71.0	93.5	12.7
80	312	0.181	5.47	54.8	79.5	17.6
100	327	0.178	4.43	44.3	70.8	22.1
120	341	0.168	3.73	37.3	63.1	27.8
140	353	0.158	3.22	32.2	57.0	34.0
160	363	0.155	2.83	28.3	52.8	39.6
200	381.8	0.145	2.29	22.9	46.0	52.3
250	400.9	0.139	1.84	18.4	40.4	68.0
300	417.3	0.134	1.53	15.3	36.1	85.3
350	431.7	0.130	1.32	13.2	33.0	101.5
400	444.5	0.125	1.16	11.6	30.4	119.5
450	456.3	0.123	1.03	10.3	28.4	137.5
500	467.0	0.121	0.93	9.3	26.8	154.0
600	486.2	0.115	0.77	7.7	23.7	193

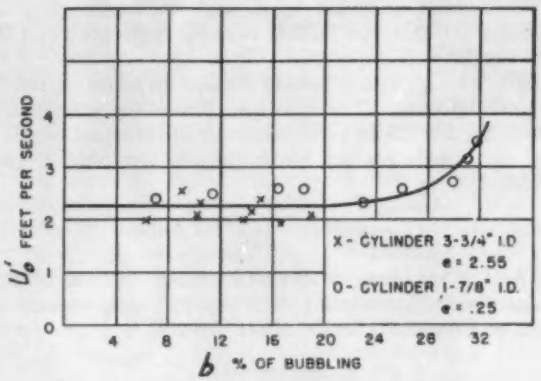

Fig. 4—Steam bubble velocity in water at 100 C

These results show that the bubble contact heater in this case is much more profitable than the tube heaters (about 3 to 3.5 times cheaper).

As steam pressure rises above 300 psia, bubble contact heater would be more and more economical because of their decreased size, very simple construction, and less rigorous temperature conditions. In Table III are listed other calculated data for bubble contact heater.

Fig. 5 shows how the size of the bubble contact heater is affected by an increase in steam pressure at the same output and heat exchange. In contrast, the size of tube heaters is chiefly determined by the amount of heat ex-

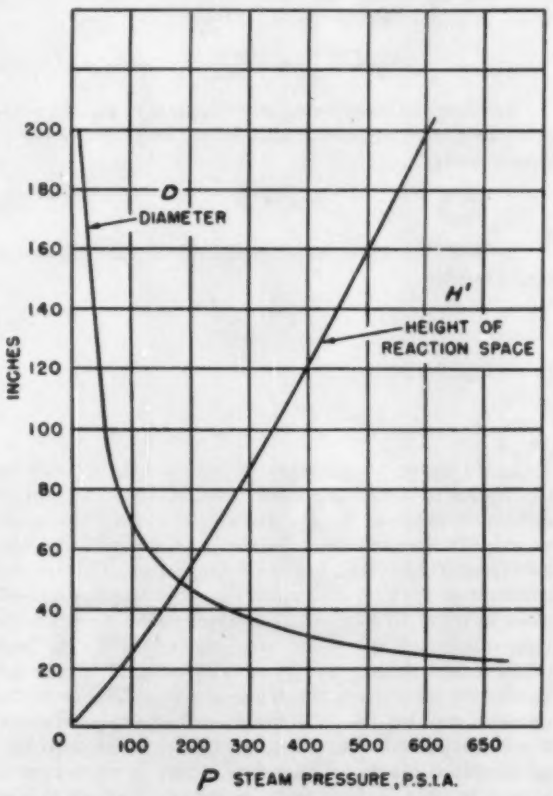

Fig. 5—Size of bubble contact heater calculated for inlet steam rate of 36,000 lbs. per hr

change and does not depend on the steam pressure, because the steam enthalpy varies little with changes in steam pressure. As in Table III, it is assumed that heat exchange is constant (35,000,000 Btu per hr), and the size of the tube heaters (36 to 270 in.) remains almost constant, so the tube heater can be compared with the bubble contact heater for several degrees of steam pressure.

Conclusion

The average steam bubble velocity in water at 100 C was measured by an integral method and found to be 2.25 fps. This velocity remains almost constant to 25 per cent of bubbling. If the percentage of steam bubbles in the mixture exceeds 25 per cent, the union of bubbles into streams increases. The permissible cross-sectional area steam velocity in the bubble contact heater may be approximately 0.6 fps, in water at 100 C.

The heat transfer coefficient between steam bubbles and water per cu ft of steam bubbles in water was estimated to be 203,000 Btu per (cu ft) (hr) (deg F) at atmospheric conditions.

On the basis of the experimental data, it was found by calculation that bubble contact heaters are not practicable at low steam pressure, but may be effective when the steam pressure is greater than 120 psi. Bubble contact heaters are especially profitable at high pressures (above 300 psi.)

The heating system in power plants may be considerably simplified by replacing expensive high-pressure tube heaters in the last stage to the bubble contact heaters. At the same time, any special apparatus for deaeration and drain cooling is eliminated.

Nomenclature

a = cross-sectional area of cylinder, sq cm
b = steam bubbles in mixture (bubbling coefficient), vol. per cent
c = constant
d = diameter of steam bubble, cm
e = bubble path elongation
E = kinetic energy, g-cm
h = height of water column, mm
h' = height of mixture (water + bubbles), mm
Δh = growth of water in cylinder, mm/min
k = direct contact heat transfer coeff., kcal(cu m) (hr) (C)
m = mass of water, g
n = number of bubbles
r = radius of steam bubbles, cm
s = total surface of steam bubbles, sq cm
t_{st} = temp of steam, C
t_w = temp of water, C
Δt = mean temp difference between steam and water, C
u = steam velocity at cross-section of cylinder, cm/sec
u_0 = cross-section steam velocity in 100 C water, cm/sec
u' = steam bubble velocity in water, cm/sec
u_0' = steam bubble velocity in water at 100 C, cm/sec.
u_w = water velocity, cm/sec
v = vol of inlet steam, cc/sec
v_b = vol of a single bubble, cc
α = coefficient of steam absorption, grams/(sq cm of steam bubbles) (min) (C)
β = coeff. of steam absorption, g/(cc of steam bubbles) (min) (C)
ρ_{st} = density of steam, g/cc
ρ_w = density of water, g/cc
ν = kinematic viscosity of water, cs
τ = time, sec
A = cross-sectional area of apparatus, sq ft
C = constant
D = diameter of apparatus, in.
D_1 = inside diameter of ring baffle, in.
D_2 = diameter of disk baffle, in.
d_i = diameter of steam bubbles, in.
e = bubble path elongation
G = weight of inlet steam, lb/hr
H = height of water column, in.
H' = height of mixture (water + bubbles), in
H_b = baffled height, in.
L = total length of zigzag path, in.
N = number of baffles
P = steam pressure, lb/sq in. abs
Q = heat exchanged, Btu/hr
q = direct contact heat transfer coeff, Btu/(cu ft) (hr) (F)
q_s = surface coeff. of heat transfer, Btu/(sq ft) (hr) (F)
R = reaction space, cu ft
T_{st} = temp of steam, F
T_w = temp of water, F
ΔT = mean temp difference between steam and water, F
U = steam velocity at cross-section of apparatus, fps
U_0 = cross-section steam velocity in 100 C water, fps
U' = steam bubble velocity in water, fps
U_0' = steam bubble velocity in water in 100 C, fps
V = volume of inlet steam cu fps
V_a = volume of air, cu fps
v = specific volume of steam, cu ft/lb
Z = spacing between baffles, in.

BIBLIOGRAPHY

(1) Geddes, R. L., *Trans. Am. Inst. Chem. Engrs.* **42,** 907 (1946).
(2) Kotelewskij, G. P., *J. Chem. Promyshlenosty* **XIV,** 664 (1937); XVI' 28 (1939).
(3) O'Brien, M. P., and Gosline, J. E., *Ind. Eng. Chem.* **27,** 1436 (1935).
(4) Stokes, G. G., Math. and Phys. Papers, **111,** 55.

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MORE than 600 registrants attended the Sixth Symposium (International) on Combustion sponsored by the Combustion Institute at Yale University, August 19–24, inclusive. These registrants came from all over the world to hear a program of papers presented by authors from both sides of the Iron Curtain and from the Far East and India.

To one who has attended the meetings of the power generation industry the papers would be classified as primarily research in character. The aviation and rocket scientists in attendance felt, however, that much of the material was already in the application stage. Those papers which in our opinion may be of interest to the power field are abstracted below.

In addition three round-table discussions were scheduled covering: (1) future problems in combustion research by representatives of eight nations, (2) high-speed reactors with five discussion leaders under the chairmanship of a sixth scientist, (3) flame stabilization in fast streams, again with five discussion leaders, and a chairman.

High-Speed Reactors

"Combustion Studies in a Stirred Reactor" by **H. C. Hottel, G. C. Williams** and **M. L. Baker,** M.I.T., covered the investigation of high output combustion phenomena by the study of the behavior of steady flow combustion systems in which the reacting gases are mixed as rapidly as possible with the feed gases as the feed is admitted to the reactor. A spherical reactor with the feed ports placed on the surface of a sphere inside the reaction vessel and concentric with it was employed. The purposes of the investigation were: to compare the reactivities of two fuels having identical physicochemical properties but different chemical structures, including an evaluation of reaction order, energy of activation and effect of pressure; to examine by calculation the effect of various assumptions as to kinetics or rate constants on operating characteristics of stirred reactors.

The reaction vessel used was an insulated sphere four inches in inside daimeter provided with a $^3/_4$-in. diam concentric feed source. Gases were admitted at sonic velocity through eighty uniformly spaced feed ports either 0.030 or 0.055-in. diam and left through 60 symmetrically placed $^1/_4$-in. outlet holes.

It was established that the structural formula has a pronounced effect on the blowout characteristics of the reactor. On the fuel-lean side of stoichiometric, blowout flow rates for mixture A were approximately 1.75 times greater than blowout flow rates for mixture B at corresponding fuel-air ratios in spite of the fact that the feed stream was preheated approximately 100 F more for fuel B than for fuel A.

It was observed that the blowout flow rate is a function of the size of the inlet ports and from this observation it was deduced that the mixing time of the inlet gas streams with the gases residing in the reactor was not an insignificant fraction of the total residence time. Gas sampling traverses verified this with a decrease in hole diameter increasing flow.

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A paper prepared by the late **W. J. Wohlenberg,** Yale University, "A discussion of the Relations Existing Between Limiting Energy Release Rates and Blowout for Hydrocarbon Fuels," is founded upon the assumption that if $\bar{H}$ represents the time mean rate of energy release over the interval of fraction burned from zero to x then ratio $(\bar{H}/x)$ is proportional to the rate of input (fuel plus air) required to yield release rate $\bar{H}$ for a constant mixture ratio (air/fuel) at entrance.

Then this procedure is applied to a pattern of results derived by the author's equation, which is said to show the variation in values of energy release rate with variation of the principal energy coordinates that govern the release rate. These results are based on dodecane and cover mixture concentrations from the stoichiometric through a portion of the lean side to an air supply which is about two times the stoichiometric air supply. It is found that the locations in this pattern where "reaction-rate-induced blowout" is imminent do not coincide with those where the energy release curves peak. The former are beyond the latter in the direction of decreasing fraction of fuel burned, the energy release rate at blowout being somewhat less than at the peaks of the energy curves.

The reported results for the lean side of the mixture have been compared with results derived from a formulation by Longwell and Weiss.[1] Both formulations involve the usual form of activation energy. Values of constants in the Longwell-Weiss equations are based on experiment, whereas those in the author's equation are based on the molecular constants of the kinetic theory of gases. Of special importance in evaluating the basis for comparison is the fact that the reaction chamber conditions provided by the controls in the Longwell and Weiss investigation were virtually identical with those assumed by the author when integrating his equations. These assumptions include a completely stirred mixture, i.e., molecularly uniform distribution at entrance, and instantaneous rise of temperature from entrance to flame temperature level. Longwell and Weiss superimpose high turbulence at the entrance to accomplish the latter; the author assumed this condition to exist. He also assumed zero heat loss from the flame; Longwell and Weiss reduced this loss to a minimum with insulation.

[1] Longwell, J. P., and Weiss, M. A.: "Heat Release Rates in Hydrocarbon Combustion." Joint Conference on Combustion, M.I.T., June 1955. Published by The Institution of Mechanical Engineers, 1 Birdcage Walk, Westminister London, S.W. 1.

Structure and Propagation of Laminar Flames

The very fundamental assumption that has been accepted in developing flame theory to date is now under definite challenge. **Theodore von Kármán,** Pasadena, Calif., in his paper "The Present Status of the Theory of Laminar Flame Propagation" went to the heart of the matter by stating: "the theory has been based on applying equations of conservation of mass and energy to a one-dimensional flow of a mixture which is unburned at the cold boundary and approaches an equilibrium state at the hot boundary."

Mr. von Kármán points out the wealth of assumptions such a theory blindly accepts, for example, "that the flow can be considered as such of a continuous gas, that the chemical kinetics furnishes the necessary expressions for the chemical changes entering in the conservation equations and that the transfer phenomena are characterized by full knowledge of the heat transfer coefficients and the laws of diffusion. Further, the law of conservation of momentum is taken care of by the assumption that pressure variations can be neglected." Later, says Mr. von Kármán, when one introduces an ignition temperature for the reactions involved, i.e., the hypothesis that no chemical change takes place below a given temperature, a highly questionable assumption has been added. There is no physical reason for assuming a definite ignition temperature.

The first part of Mr. von Kármán's paper deals with the discussion and successful elimination of this difficulty based on his own and A. G. Millan's joint investigations. The second part presents various attempts to overcome the difficulties of solution by mere computation or by partially analytical methods. Lastly, the author discusses certain physicochemical assumptions which may simplify the problem, especially in the case of chain reactions, and compares experimental material in the light of these physicochemical assumptions.

D. B. Spalding, Imperial College, London, England, in his paper "Ends and Means in Flame Theory" takes up much the same viewpoint as expressed above. As Mr. Spalding

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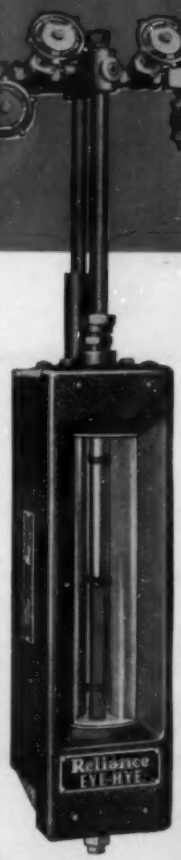

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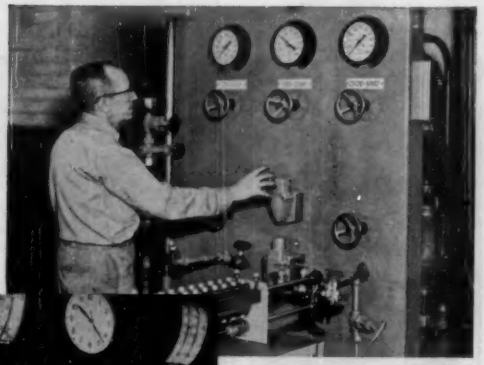

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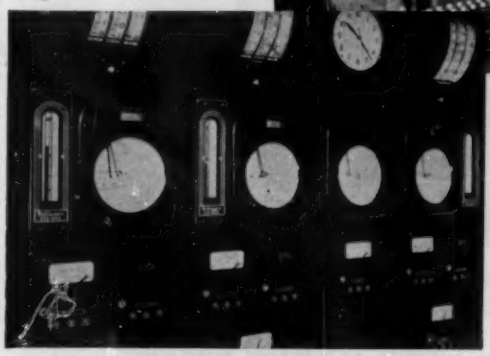

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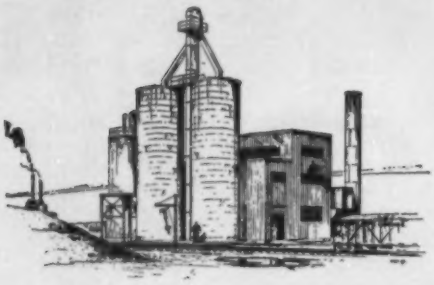

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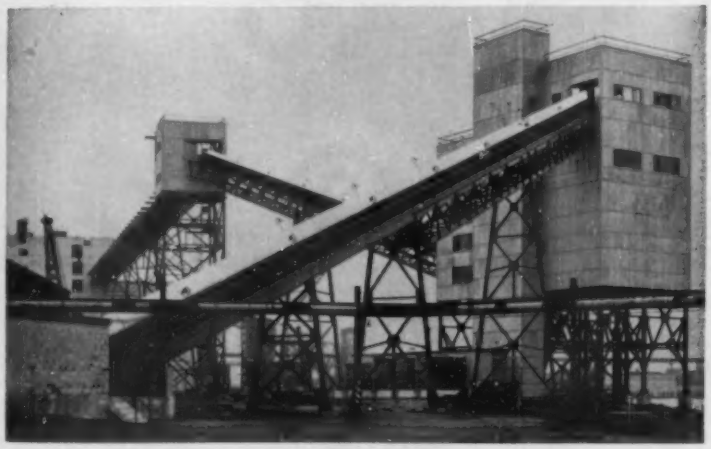

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states, "if the reaction proceeds by way of a single step, numerical solution is easy but the labor of computation becomes progressively greater as the number of intermediate radicals increase. So far few reactions have been studied that compare in complexity with those which chemists believe obtain in real flames."

In the first part of this paper the author has phrased his comments for the benefit of the non-specialist. The so-called "short-cut theories" based on intuition to avoid the labor of getting a full answer by postulating that flames are dominated by a single property or process, e.g., "excess enthalpy" are of negative value, in his opinion. Further the aim of flame theory to predict dependence of flame properties on variations in combustion chamber geometry and flow pattern has its origin in the desire of the engineers to develop plants quickly and cheaply. Simple reaction kinetics are not enough in this case. Rather heat losses, boundary layers, recirculation and turbulence, among other factors, must be considered. Very little work has been done on these or on the fact that flame has two or three space dimensions and may be unsteady in time.

The second part of the paper treats the "chemist's" and the "engineer's" flame problems in a uniform way. It is pointed out that analytical, numerical and analogue methods are available for dealing with heat conduction and diffusion without convection —processes which are most naturally described by second-order Poisson-type equations. Flame theory has failed to use these methods because for the one-dimensional flame a transformation to a first-order equation is possible and superficially attractive. A transformation that the author questions seriously and one that leads to introducing a fictitious "catalyst plug" at the hot boundary to transfer a small but finite amount of heat upstream.

A. Van Tiggelen and J. Deckers, University of Louvain, Belgium, in their paper "Chain Branching and Flame Propagation" advanced the belief that the employment of chain branching is a much easier reaction to encompass in discussing the kinetics of flame propagation in gaseous mixtures than any other approach. The losses of chain-breaking that occur in an ordinary prime chain initiation is held up as one particular reason. Similarly the chain branching reactions can be expressed in very simple equations which lead to a basic equation for flame velocity where the activation energy of the branching process is the important parameter.

Structure and Propagation of Turbulent Flames

In order to test existing theories of turbulent burning velocity, and particularly to search for flame-generated turbulence, measurements were made of burning velocity as a function of height in Bunsen flames. A stoichiometric mixture of Pittsburgh natural gas and air was studied at 10,000, 25,000, 50,000 and 100,000 Reynolds number of approach flow, with a $1^1/_4$-in. burner tube. Several improvements in technique were presented by **J. Kenneth Richmond, Joseph M. Singer, E. B. Cook, James R. Oxendine, Joseph Grumer** and **David S. Burgess,** U. S. Bureau of Mines, Pittsburgh, in their paper "Turbulent Burning Velocities of Natural Gas-Air Flames with Pipe-Flow Turbulence."

It was found that there was much greater divergence of approach gas flow in the presence of these flames than would exist in a similar flow without a flame, and the flow divergence is always accompanied by an increase in static pressure which is many times larger than that corresponding to the laminar flame pressure. Further tests, however, indicate that flame-generated turbulence, if any, is quite small.

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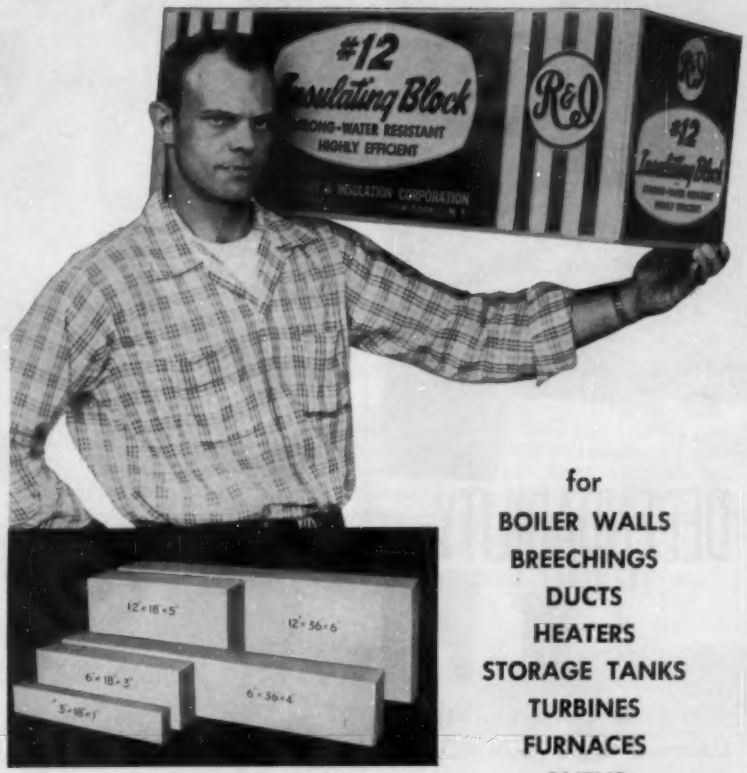

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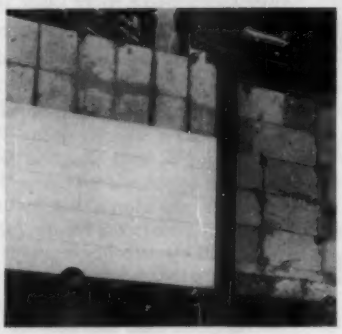

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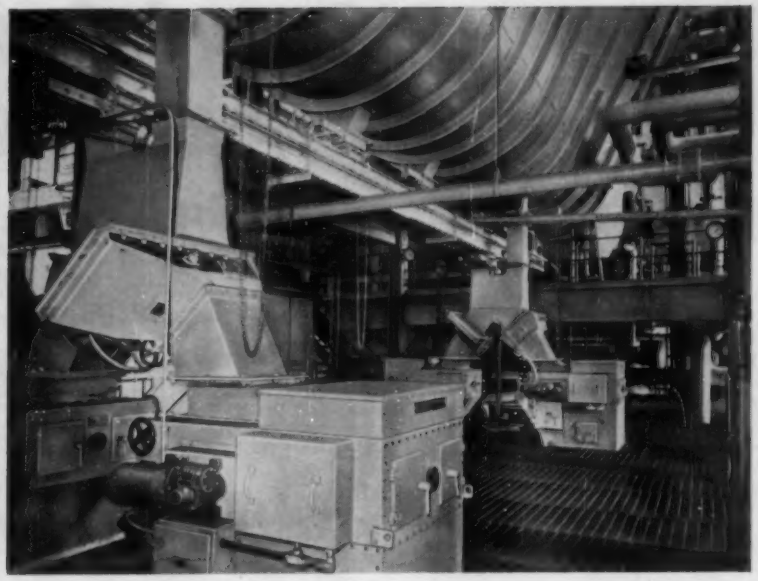

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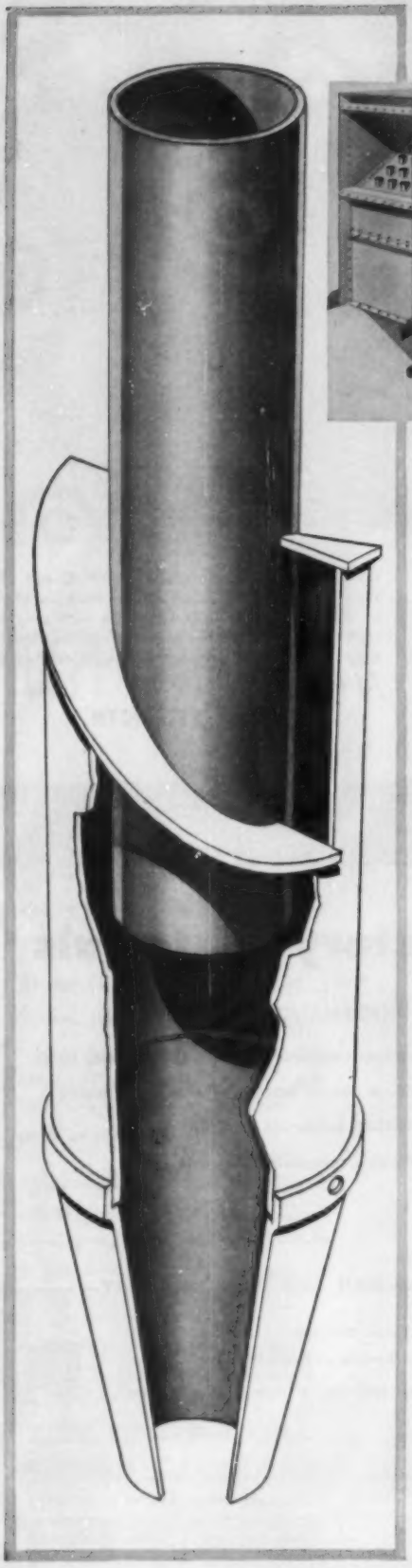

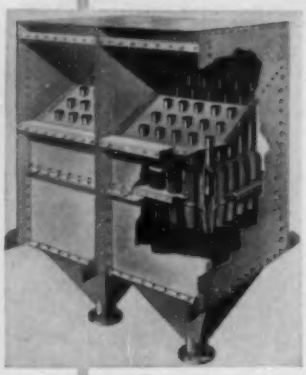

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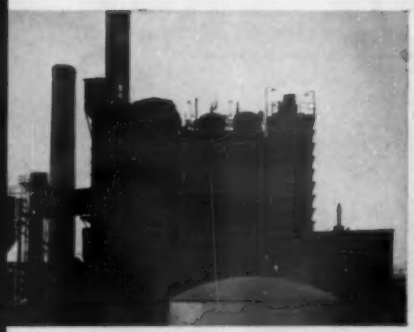

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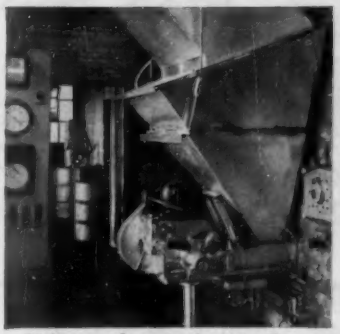

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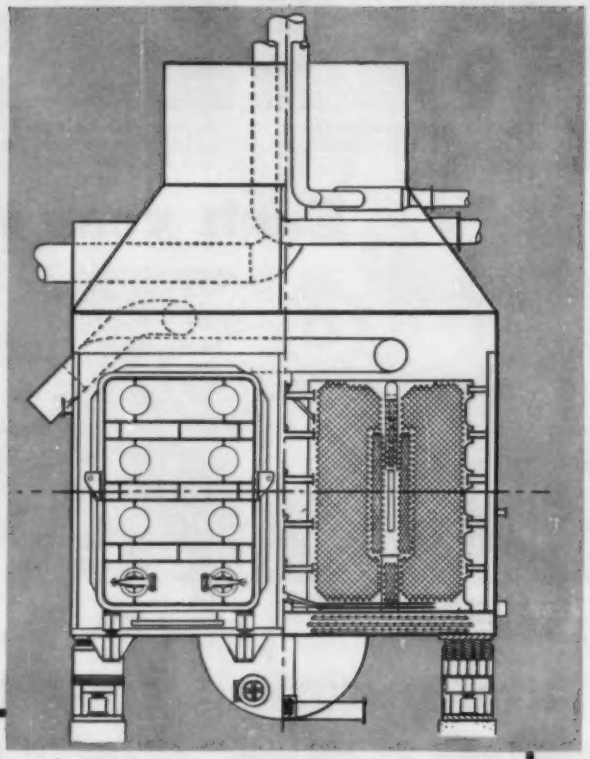

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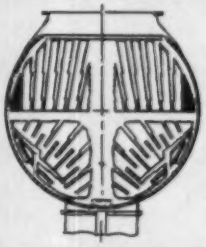

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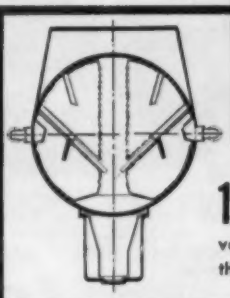

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Of all the methods used by industrial plants and public utilities to stockpile and reclaim large tonnages of coal, none does the job as completely and efficiently as the Euclid Twin-Power Scraper.

The "Twin" is entirely self-loading in loose, highly compacted, wet or even frozen coal. It builds, extends or raises a well drained and compacted stockpile . . . carries big loads at speeds up to 30 m.p.h. Coal handling with Euclid Twin-Power Scrapers is much more flexible and economical than using other methods and equipment.

Many industrial concerns and public utilities have cut their coal handling costs with these large capacity, versatile " Eucs". If you want maximum flexibility at minimum investment and operating cost, call your nearby Euclid dealer for a production and cost estimate. There's a mighty good chance he can show you the way to lower coal handling costs!

These are some of the owners who are using Euclid Twin-Power Scrapers for coal handling:

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Detroit Edison Co.
Electric Energy, Inc.
Great Lakes Carbon Co.
Illinois Power Co.
Jersey Central Power & Light Co.
Kansas Power & Light Co.
Northern States Power Co.
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EUCLID DIVISION GENERAL MOTORS CORPORATION, Cleveland 17, Ohio

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FOR MOVING EARTH, ROCK, COAL AND ORE

ash handling costs *Cut*

with ABK® METAL

pump life increase—5 to 1

. . . pipe life increase—3 to 1

Pumping 300 tons of ash per day at a large midwestern power plant, pump shells of alloy steel were averaging only six months life. Then pump shells were specified in ABK Metal—a nickel-chrome iron alloy of controlled structure with outstanding abrasion resistance. Installed in 1945, these pumps gave 31 months of service and handled 140,000 tons of ash . . . a pump life increase of over 400%.

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For economical handling of your wet or dry ash specify ABK Metal pump casings and impellers, pipes, elbows and fittings, liners, injector nozzles and similar equipment.

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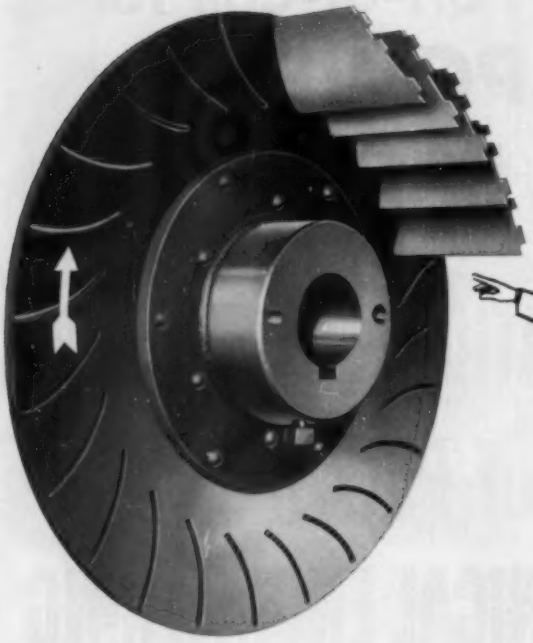

Something different (and decidedly better) distinguishes this wheel

ONE-PIECE blades extend THROUGH slots in the centerplate — then are welded both front and back on both sides of the centerplate.

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Sure, you can perhaps get by with lesser construction. That is, a wheel with separate blades on each side of the centerplate.

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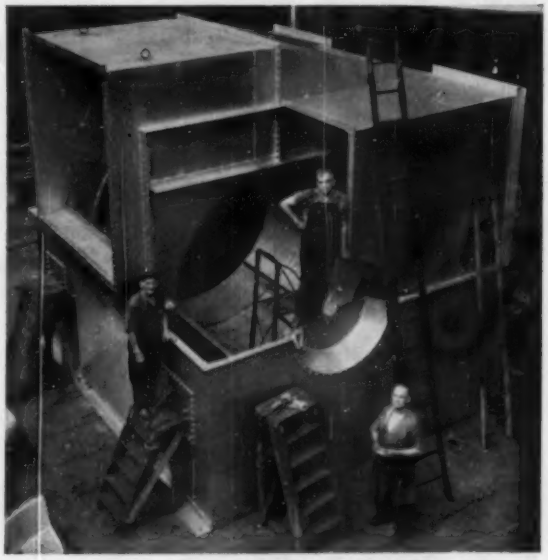
Additional advantages of choosing Clarage Type RT equipment are shown in Catalog 901. Write for it today. CLARAGE FAN COMPANY, Kalamazoo, Michigan.



Clarage builds for many of the biggest and most exacting air handling jobs. This Type RT fan was constructed for induced draft service in a Porto Rican sugar refinery.

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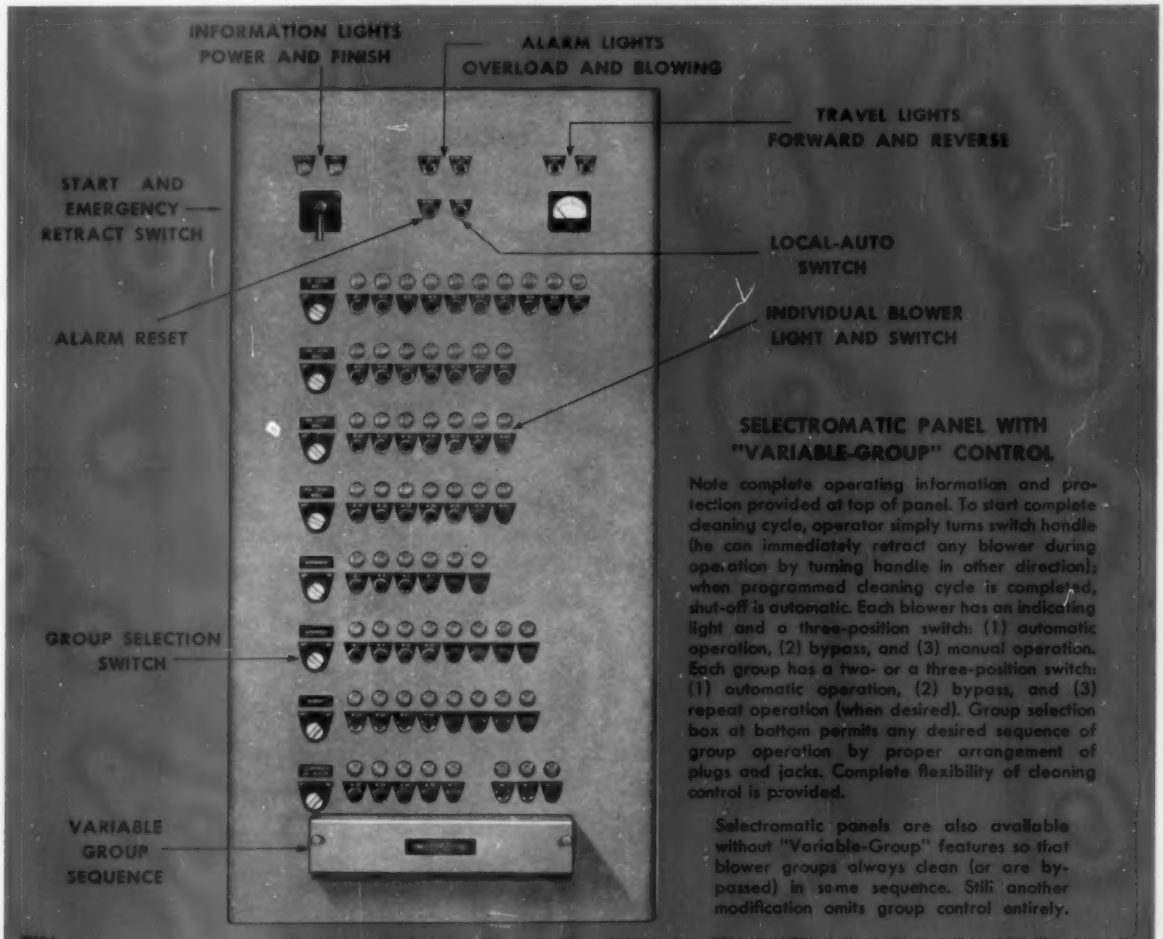
GROUP CONTROL, is designed to accomplish more direct operation of *functional groups* of blowers rather than individual units. Group control is applicable where there is a large number of furnace wall, superheater, reheater and economizer cleaning units which rarely warrant blowing by single units but can rather be operated in groups representing each level of such blowers.

The Group concept can readily be arranged to have physical similarity to the boiler unit itself, with the groups starting at the lowest furnace level and progressing upward through the furnace wall blower levels and on through the superheater and reheater banks, economizer and air heater in logical group sequence.

A Diamond Selectromatic* Panel will provide the flexible blower control needed for the most efficient, economical and dependable cleaning of ANY boiler. The automatic sequential operation is easily and quickly changed to meet variable cleaning conditions in the unit. Operators know at all times the operating conditions of the blowers (see top of left page). Protective devices include automatic blower retraction on motor overload, blowing medium failure, and current failure (after restoration). Once a cycle is selected and initiated by the operator, no further attention is needed.

*Selectromatic is a registered trade mark that is a contraction of the functional features of these controls: selective—electric—automatic.



SELECTROMATIC PANEL WITH "VARIABLE-GROUP" CONTROL

Note complete operating information and protection provided at top of panel. To start complete cleaning cycle, operator simply turns switch handle (he can immediately retract any blower during operation by turning handle in other direction); when programmed cleaning cycle is completed, shut-off is automatic. Each blower has an indicating light and a three-position switch: (1) automatic operation, (2) bypass, and (3) manual operation. Each group has a two- or a three-position switch: (1) automatic operation, (2) bypass, and (3) repeat operation (when desired). Group selection box at bottom permits any desired sequence of group operation by proper arrangement of plugs and jacks. Complete flexibility of cleaning control is provided.

Selectromatic panels are also available without "Variable-Group" features so that blower groups always clean (or are bypassed) in same sequence. Still another modification omits group control entirely.

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and second largest
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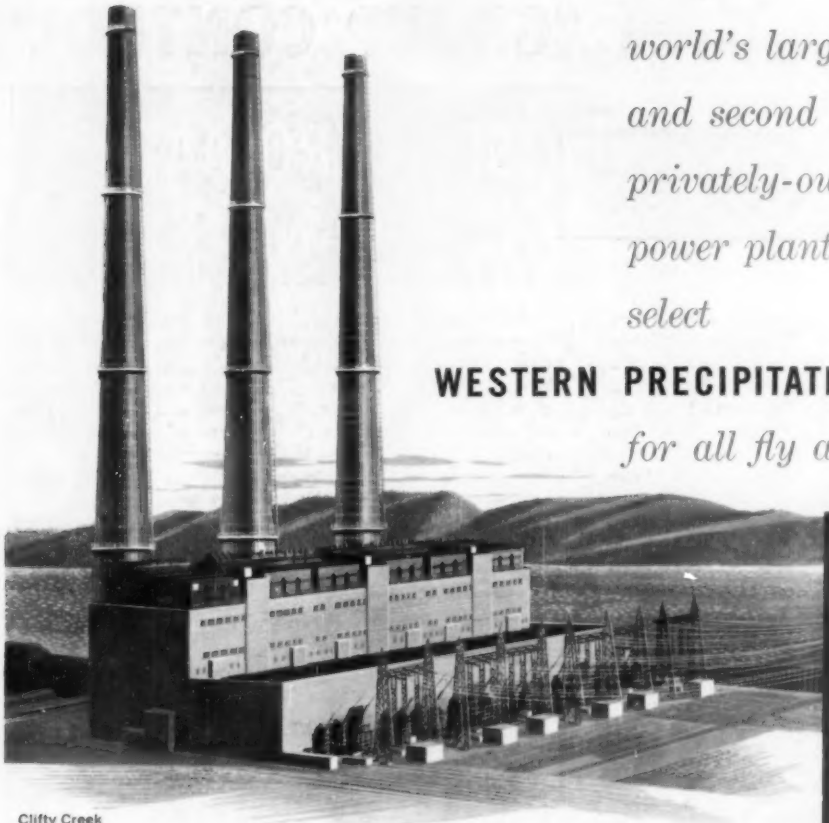
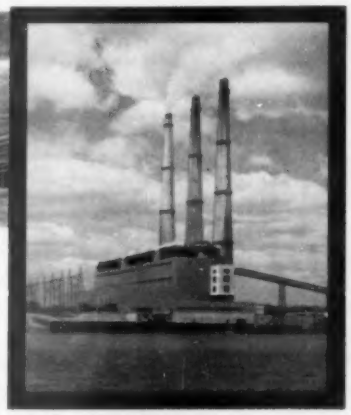
for all fly ash recovery!



Clifty Creek



Kyger Creek

In the Ohio Valley area a new industrial miracle is now completed. Fifteen private utility companies have joined forces as the Ohio Valley Electric Corporation to construct the world's largest and the world's second largest privately-owned electric power plants.

The project is not only the largest single undertaking in the entire history of the electric utility industry, but also one of the most modern. *And it is highly significant that, with so much at stake, Western Precipitation integral CMP (Combination Multiclone-Precipitator) Units were selected to handle the entire fly ash recovery operation.*

At the larger of these two modern new plants—Clifty Creek Plant near Madison, Indiana—six CMP Units are installed. At the other—Kyger Creek Plant near Cheshire, Ohio—five CMP Units are installed. In both plants the recovery operation is identical. Flue gases from the boilers first pass through Multiclone sections where the heavier suspensions are mechanically recovered by small-tube *cyclonic* separators. The partially-cleaned gases then flow on into Cottrell Electrical Precipitators where final clean-up of even the extremely fine particles is effected.

Result

—by combining advantages of both mechanical and electrical recovery methods into one compact coordinated installation, very high recovery efficiencies are obtained at low installation and operating costs. And the CMP has the further advantage that overall efficiency remains uniformly high regardless of boiler loads—an important advantage not found in other types of recovery equipment.

Western Precipitation offers—in ONE experienced organization—years of progressive "Know-How" in all three basic types of recovery equipment . . . *electrical* (COTTRELL), *mechanical* (MULTICLONE) and *filter* (DUALAIRE). Not only does this assure you an unbiased recommendation on the type best suited to your particular requirements, but also assures maximum performance when integrating two types of equipment into one overall system.

We are equipped to handle complete "turnkey" installations—or any phase of a dust, fume or fly ash control problem. Throughout major industrial areas of the United States and Canada, we are as close as your telephone. May we serve you?

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